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FLIGHT TEST RESULTS OF A POWERED PARAFOIL SYSTEM (AEROFLYER)

A-E-R-O

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AIR FORCE FLIGHT DYNAMICS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
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WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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FOR THE COMMANDER

Ambrose B. Nutt

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Eighty flight tests of the AeroFlyer are carried out in order to demonstrate that it can fly and in order to obtain flight performance data. All of these tests are summarized with particular emphasis on the data obtained from the three flight tests at Wright Field. These demonstrate that the AeroFlyer can take off directly from the ground, climb, turn right and left, glide and achieve a precision soft landing. The data from the three flights at Wright Field is analyzed and compared with performance predictions. The turns were

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accomplished by rudder, by wing deflection, and by combinations of both. The representative flight velocity is 29 mph and the rate of climb is 60 ft/min for an AeroFlyer weighing 579.3# using a 400 sq. ft. Parafoil. The horsepower required for level flight was 12. The minimum radius of turn demonstrated was 175 ft. and the nominal landing roll was estimated to be less than 20 ft. This performance data is used to predict optimum parafoil performance for flight system weights ranging from 10# to 10,000#.

FOREWARD

This report was prepared by A-E-R-O, P.O. 1676, San Luis Obispo, California, 93406, under U. S. Air Force Contract Number F33615-73-C-3151. This contract was initiated under Project 6065, Performance and Design of Deployable Aerodynamic Decelerators, Task 6065 01, Terminal Descent Parachutes for Tactical Air Drop and Military Vehicle Recovery. The work was administered under the direction of the Recovery and Crew Station Branch (AFFDL/FER) of the Air Force Flight Dynamics Laboratory at Wright-Patterson Air Force Base, Ohio. Mr. R. Speelman and Mr. M. Higgins served as project engineers during the duration of the effort.

The author was Dr. John D. Nicolaides*, President of A-E-R-O. The author is indebted to Dr. Charles Ingram for directing all of the flight tests and to Mr. W. Miklos and Mr. M. Garsik for their loyal assistance.

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LIST OF SYMBOLS

α	angle of attack (deg)
γ	angle that the flight path makes with the horizontal (deg)
η	dimensionless thrust factor
$\underline{\eta}$	thrust ratio factor
θ	thrust angle; angle that the thrust line makes with the horizontal (deg)
μ	ground resistance factor
ρ	density of air (slugs/ft^3)
A	planform area of Parafoil airfoil (ft^2)
AR	aspect ratio
C_D	coefficient of drag
ΔC_D	additional drag coefficient due to size of vehicle and vehicle suspension system
C_L	coefficient of lift
D	drag force (lbs)
ΔD	additional drag due to size of vehicle (lbs)and vehicle suspension system
deg	degrees
fpm	feet per minute
fps	feet per second
ft	foot or feet
g	gravity
HP	horsepower
ΔHP	excess horsepower for calculation of rate of climb

LIST OF SYMBOLS (concluded)

L	lift force (lbs)
lbs	pounds force
L/D	aerodynamic lift to drag ratio
m	mass
mph	miles per hour
ND 2.0(400)	indicates a Parafoil with an aspect ratio of 2.0 and a planform area of 400 ft^2
q	dynamic pressure, $\frac{1}{2} \rho V^2$
R/C	rate of climb available under conditions being analyzed (fpm)
T	thrust (lbs)
T_o	static thrust ($T_o = T_\theta$ at $\theta = 0$)
u	horizontal velocity; velocity in x direction (fps)
V	total velocity (fps, mph) also U when horizontal
w	vertical velocity; velocity in z direction (fps)
W	weight (= mg) (lbs)
x	horizontal inertial axis
$\ddot{x}$	acceleration along x axis
z	vertical inertial axis
$\ddot{z}$	acceleration along z axis
X	take-off distance
X_T	true take-off distance
R	ground resistance
V_S	stall velocity

I. INTRODUCTION

The age of aviation began with the flight of the Wright Brothers in 1903. From that day to this, all of the wings of aviation have been fixed rigidly to the fuselage and all the wings of aviation have been rigid.

On the 70th anniversary of the first flight of the Wright Brothers, a successful flight demonstration of a new type of flying machine took place. This flying machine, called the AeroFlyer, employed a wing that (1) was free and independent of the fuselage, (2) was non-rigid, and (3) was located approximately one span above the fuselage which contained the pilot and power plant. [1, 2]

Prior to the anniversary flight, 71 partially successful flights had been carried out and in the following summer three special test flights were successfully carried out at Wright Field in Dayton, Ohio. Fig. 1.

This report contains a brief summary of all of the test flights of the AeroFlyer with special emphasis on the data from the three Wright Field flights and on the direct take-off flight of Thanksgiving 1974.

II. AEROFLYER CONCEPT

The AeroFlyer* concept is composed of two components, a power and payload module and a separate rigid or non-rigid wing. The wing is tied to the module by one or more completely flexible lines and is located approximately one span above the module. In the current tests a non-rigid wing called the Parafoil** was used.[1-20]

It was asserted that such a machine could fly, that it was stable, and that it required only two flight controls, one for turning and one for ascending and descending. It was further asserted that such a flying machine had numerous applications ranging from the recovery of disabled pilots to the recovery of RPV's and automatic delivery of weapons, cargo and spacecraft.[7,8]

In the case of the disabled pilot, the module would consist of the pilot's ejection seat with a small jet engine underneath and with a non-rigid cloth wing packed as a back cushion. Following ejection the wing could be deployed like a parachute, the engine would light up and the pilot could fly to a pick-up point for either air snatch or soft landing.*** The pilot can either land with his seat or release from it and land like a parachutist.

In the case of the RPV recovery, the non-rigid wing would be stowed during the mission but after deployment could be flown for low speed missions and for pinpoint soft landings of air recovery.****

In the cargo case, the wing is stored prior to airdrop.[13] After airdrop and deployment the system is flown by remote or homing control to distant or standoff pinpoint landings on unprepared pads.

In the case of spacecraft or space shuttles, the wing could be stowed until atmospheric re-entry at which point deployment and powered flight could take place. This could be used to obtain scientific measurements over a large area terminating in a prevision, low speed landing.

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*All rights to the AeroFlyer concept are held by Dr. John D. Nicolaides, Patent No. 437,969, who also holds all rights to powered Parafoil applications.

**The Parafoil is a design and development of Dr. John D. Nicolaides, Patent Pending No. 105,836, and is based on the Multi-cell ram airfoil, Patent No. 3285546.

***Following the CBS program and the flights at Wright Field a great interest developed in the AeroFlyer as a sports vehicle which could be driven on the land or water and also fly.

****Numerous RPV direct powered parafoil take-offs, maneuvering flights and soft landings have been accomplished at Cal Poly since 1 November 1975.

The two fundamental questions addressed by this report are simply:

1. Can the AeroFlyer fly?
2. What are its flight performance characteristics?

In order to answer these two questions a flight test program was undertaken* which culminated in a flight demonstration for U. S. Air Force Flight Dynamics Laboratory personnel at Goshen, Indiana, on 27 April 1972. Following this demonstration, a contract was awarded to the University of Notre Dame to conduct an analysis of AeroFlyer theory and performance. This contract also included a second phase providing for flight testing. However, due to potential legal liabilities,the University did not carry out the second phase and, thus, the flight tests were carried out by A-E-R-O.

The purpose of this present contract with A-E-R-O is to answer the two basic questions set forth above by carrying out a flight test program employing two of the original flight vehicles used previously (F5, Primary Test Vehicle, and F4, Backup Test Vehicle). The results of the flight tests are reported in the sections which follow.

In order to insure success in the Air Force tests at Wright Field, two additional AeroFlyers were constructed, F6 and F7. The results of these flights are also reported.

*Dr. Nicolaides acting completely on his own authority, undertook the personal design and construction of the flight test vehicles and personally carried out the associated flight test program under FAA/SAC Numbers N-3029 and N-302ND.

III. BACKGROUND

Two unpowered glider versions and seven powered versions of the AeroFlyer concept have been designed, developed, and flight tested.* The seven powered AeroFlyer designs are shown in Figs. 2-13. Eighty test flights, listed in Fig. 1, have been carried out, and all designs have flown with varying degrees of success. In general, the AeroFlyers have been towed by car to an altitude of 50 ft. or more, released, and then flown. F5 and F7 have demonstrated a climbing and turning capability. F2 and F5 have touched down and then taken off again for short distances. F5 has touched down and then taken off and flown for another turn around the test site. F4 has taken off directly from the ground but flew only at a very low altitude and for a short distance. F7 has taken off directly from the ground and climbed to an altitude of 1,000 ft.

The flight tests of F1, F2, and F3 are discussed in greater detail in Ref. 1. However, none of these three vehicles was able to climb. F1 was able to fly straight and in slowly descending flight; F2 was able to fly straight in slowly descending and almost level flight and also could make small turns to the right and left; F3 was able to fly level but only in large continuous right turns. The test series of these early vehicles culminated in the flight demonstration of F3 at Goshen, Indiana, for the Commanding Officer of the Flight Dynamics Laboratory and other representatives of the U. S. Air Force on 27 April 1972.

The current flight test series began with the gliding flight of F4 on 7 October 1972 and ended with the direct take-off from the ground of F7 on 29 November 1974. The first flight** of F4 was as a glider and, at the request of the University, it was the last flight by a student. Thereafter, Dr. Nicolaides became the test pilot on all subsequent AeroFlyer flights and Dr. C. W. Ingram undertook the responsibilities of tow driver and test director.

*Prior to undertaking powered flights, considerable design, development, and testing of the Parafoil had been successfully carried out as a kite,[3] as a hang glider,[8] and as a jump parachute.[10,11,12,16]

**Flight No. 29, 7 October 1972

IV. DESCRIPTION OF TEST VEHICLES AND FLIGHT SUMMARY

A. F1, F2, and F3 Test Vehicles

The F1, F2, and F3 test vehicles are shown in Figs. 2-6 and are described in Ref. 1 .

B. F4 Test Vehicle

The F4 test vehicle was a major re-design of the F3 vehicle using the same Rockwell engine and part of the airframe. The F3 test vehicle, while relatively simple and neat in appearance, Figs. 7-8 , had a number of disadvantages as a flight testing platform. First, due to its tricyclic landing gear, it had a tendency to tilt over like a wheelbarrow on landing. Second, the pusher prop configuration made launching difficult due to the possible entanglement of the propeller with the wing's suspension lines. Third, the wake of the pilot and vehicle reduced the propeller efficiency. Fourth, the stick and boom control system was very complex and led to a few serious flight accidents. Lastly, the machine was unduly heavy due to landing gears, boom design, and peripheral build-up of components such as control panel, tow hitch, gas tank, engine cowling, wheels and back-up multiple control systems. In order, therefore, to provide a lighter vehicle with a more efficient propulsive system and with a safer landing configuration, the F4 vehicle was constructed. Fig. 7.

The first version of F4 had a high bar and a fore and aft roll safety bar. It should be emphasized that neither the F3 vehicle nor the F4 vehicle employed any horizontal or vertical stabilizers or any rudder. All control was achieved by wing warping and deflection. The various flights of F4 are listed in Fig. 1.

The flight tests revealed that F4 was quite stable and readily maneuverable, both in turns to the right and in turns to the left. It achieved excellent flaring on landing. In general, it was a big improvement over F3, which could fly only in right hand turns. The F4 vehicle was heavy and the Rockwell engine was, therefore, unable to provide either sustained level flight or any significant climb. Accordingly, the F4 vehicle was re-designed during the winter of 1972-73 so that by March 1973 a new and lighter F4 vehicle was available. This re-designed vehicle had a lower bar and the fore and aft safety bar was removed. The gas tank was changed, et al. This lighter F4 vehicle was flown extensively during the 1973 season. Figure 8. Four flights took place on 15 August which are recorded in the CBS 60-Minute Program shown on Easter Sunday, 1974. These flights demonstrated controllability, right and left turns, and the ability to fly level and land easily. The F4 vehicle was unable to demonstrate sustained climb. All of these flights have been analyzed and the

difficulties in climb are believed to be due to pilot inexperience and to certain minor but correctible deficiencies in the vehicle. Considerable improvement in the flight of F4 was accomplished in November of 1973 when the 400 sq. ft. wing was used. This vehicle was able to demonstrate limited direct take-off capability, however, on flight #68 it was hit by a strong cross wind and was driven sidewards into the ground where it rolled over several times causing damage to the vehicle and a broken propeller. The subsequent two flights of this vehicle permitted a check of the trim of the 400 sq. ft. Parafoil which was optimized, thereby allowing the subsequent excellent flight of F5 (Flight #71). No additional flights of F4 were carried out and it was held in reserve as a possible back-up flight vehicle for the Wright Field tests.

C. F5 Test Vehicle

The F5 vehicle shown in Fig. 9 is a major redesign of the original F2 vehicle shown in Figs. 3 - 4 and in Ref. 1. The F5 had a new engine, new landing gears, a forward location of the pilot's seat, a larger rudder, and used four wheels instead of three. However, the three flights of the F5 on 10 June 1973 were all near disasters due to over controlling by the pilot. The subsequent flights in September and October were not much better.* However, by November of 1973 both the pilot and the vehicle were improved and on 10 November an excellent flight was achieved which demonstrated sustained level flight, numerous right and left turns and short periods of slow but steady climb. The vehicle was also extremely maneuverable.

In December of 1973 two flights of the F5 vehicle were carried out using the larger and aerodynamically superior 400 sq. ft. Parafoil. The flight of 1 December was the first truly successful flight of the AeroFlyer. The vehicle was able to demonstrate sustained climb as well as maneuverability with both rudder and wing deflection controls. Further, the vehicle was able to be landed with precision and with ease. Accordingly, the Air Force Flight Dynamics Laboratory was so advised and a special demonstration flight was arranged for the 17th of December, Figure 10. This flight of the AeroFlyer was recorded by CBS and was also shown on their Easter program, 1974. The Air Force recommended that flight tests be performed at Wright Field where phototheodolite data and sequence still photographs could be taken and processed to obtain accurate measurements of AeroFlyer flight performance. The results of the Wright Field tests will be presented and discussed in subsequent sections.

*The landing on Flight No. 59 resulted in a bent frame, broken pilot seat, and bent landing gear. The pilot broke his pelvis.

D. F6 Test Vehicle

The F6 test vehicle is a redesigned version of F4, again using the Rockwell engine, Figs. 11 - 12. The first flight was in May of 1974 where the main frame was bent. The second flight of 2 June, while successful in achieving right and left turns and level flight, demonstrated only marginal climb. Thus, F6 was set aside and held in reserve as a second back-up vehicle for the Wright Field tests.

Therefore, by the Spring of 1974 three AeroFlyers, a primary F5 and two back-ups, F4 and F6, were all checked out and available for flight tests at Wright Field. Also checked out for flight testing were two Parafoils, 2.0 (360) and 2.0 (400)*.

E. F7 Test Vehicle

The F7 test vehicle was a radical departure from previous vehicle designs. The fuselage was fabricated from tubular steel, the suspension system dimensions became more representative of automotive systems, the propeller was driven by a Hirth engine with drive belt system, and the horizontal and the vertical tail surface areas were increased. Flight test #79 indicated a need for further increases in rudder area and engine modifications. Flight No. 80 was conducted after installing a larger rudder area, tightening the engine power belt and checking engine rpm and power. Flight No. 80 resulted in the first demonstration of a self-powered takeoff capability and after the takeoff, a rate of climb of approximately 10 ft/sec was maintained until an altitude of approximately 1000 feet (AGL) was reached. After initiating a controlled descent, the pilot had no difficulty in achieving a controlled landing. Due to the wide footprint of the new suspension system, there was no tendency to roll or tumble on landing. This flight was a complete success. This vehicle was not yet available at the time of the Wright Field tests.

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*These designations refer to aspect ratio of 2.0 and areas of 360 and 400 sq ft, respectively.

V. WRIGHT FIELD FLIGHT TEST PROGRAM

The purpose of the flight tests at Wright Field, Fig. 14, was twofold:

1. To demonstrate that the AeroFlyer can fly, and
2. To obtain accurate flight performance data.

Various specific goals were sought in the flight test program. They are listed below in the order of planned execution:

1. Towed take-off*
2. Application of full power and demonstration of sustained climb to altitude
3. Demonstration of climbing rudder turns
4. Demonstration of climbing wing deflection turns
5. Demonstration of sustained level flight
6. Demonstration of level flight rudder turns
7. Demonstration of level flight wing deflection turns
8. Demonstration of combined rudder and wing deflection turns
9. Demonstration of gliding flight at minimum power for L/D
10. Demonstration of full power recovery from gliding flight
11. Demonstration of touchdown and take-off
12. Demonstration of controlled approach to landing at predetermined landing sites
13. Demonstration of controlled landing
14. Demonstration of power shut down and Parafoil final deflation
15. Demonstration of direct ground take-off and climb

On all of the flights the camera coverage included two station phototheodolites for space positioning data, sequence still cameras, 16 mm films and 35 mm still camera coverage. Communications were by radio to permit pilot reports on data and maneuver sequencing during the flight for tape recording on the ground. AeroFlyer F5 was utilized on all three tests which were carried out on the 9th, 10th, and 11th of July 1974.**Some of the data which was obtained during the flight test program is discussed in the following sections.

These three Wright Field flights were flight number 76, 77, and 78 (Fig 1) but are referred to in the following sections and on the figures as flight number 1, 2, and 3.

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*For reasons of safety, all take-offs and landings used the grass areas rather than the paved runways. Also, all take-offs were of the tow type.

**Back-up vehicles F4 and F6 were not used. Back-up vehicle F7 was available at Wright Field but was not used. The flight tests of AeroFlyer F7 will be reported in a subsequent section.

VI. WRIGHT FIELD FLIGHT TEST RESULTS

The phototheodolite data obtained by the U. S. Air Force on flights 1 and 3 was reduced by the University of Dayton and is used herein. No phototheodolite data was obtained on flight No. 2.

A brief discussion of each of the three flights as obtained from the pilot, from the recorded tape transmissions, from the phototheodolites, from the sequence still photographs and from the 16 mm movies follows.

A. Brief Description of Flight #1 of 9 July 1974 (Figs. 15-18)

Following the pre-flight inspection of both the wing and the Flyer, (Figure 16), the radio communications were checked and the engine was started and run in. The subsequent ground tow, lift off, and line release were all normal, (Figure 17). Both foot control*and rudder control were used during tow as required. After tow line release, (Figure 18), only rudder control was initially used. A good steady and continuous climb was maintained for 270 seconds at a rate of climb of approximately 1 ft/sec. During this period the pilot reported an engine rpm of 3500, a manifold pressure of 0, an oil pressure of 40, and a flight velocity of 25 knots (28.7 mph, 42.2 ft/sec). During this sustained ascent, left climbing rudder turns were made of 180°, 90°, and 90°. Also, good downwind and upwind climbing flights were made. On reaching an altitude of 300 ft. at 270 sec., the pilot was again passing over the launching point where he then reduced the throttle to 3000 rpm. The velocity was 24 knots (40.5 ft/sec) with jumps to 27 knots for the subsequent slowly descending flight. Left rudder turns of 90° and 90° were subsequently made. At approximately 420 seconds, a left rudder turn of 90° was made, immediately followed by a very hard foot control* and rudder control left turn of 90° followed by a 45° left rudder turn and then followed by a 45° hard right foot deflection and rudder turn. These sharp maneuvers placed the Flyer on a course directly down the main runway and directly over the chase car. The engine rpm was then increased until the Flyer achieved level flight at an engine rpm of 3300. During the sustained low altitude chase the car measured a ground velocity of 26 mph (22.6 knots, 38.13 ft/sec). At 504 seconds an altitude of 20 ft. was reached at which point the pilot applied power and climbed to 92 ft. at 530 seconds (R/C = 2.7 ft/sec) at which point power was reduced. The best rate of climb encountered during this interval was about 4 ft/sec. Subsequently, the pilot induced a series of

*Foot control is the method for providing wing deflection and has the capability of not only providing very quick and steep turns but also the capability of flaring out on landing.

swerving divergent oscillations which terminated by an abrupt (gust?) left turn of 90° at 532 sec. Thereafter the pilot made a hard right rudder turn of 180° and returned towards the landing site area. The final approach turn was 180° using left rudder followed by a smooth descent to a soft flare landing with a ground roll less than 20 ft. On touchdown the engine was cut and the wing was deflated.

B. Brief Description of Flight #2 of 10 July 1974 (Figs. 19-22)

This flight was planned as both a data flight and a demonstration flight for interested Air Force officials. The data acquisition equipment malfunctioned and therefore the data stations were not activated.

The tow, take-off and release were normal. After tow line release and climb to approximately 200 ft., the pilot reported an engine rpm of 3500, a manifold pressure of 0, and a flight velocity of 25 knots. Later in the flight he reported 24 knots and still later he again reported 25 knots. After a climbing flight into the wind, the pilot made a 90° right rudder turn followed by a straight cross wind flight where he then made another 90° right rudder turn and a long downwind flight. Upon reaching the end of the downwind leg, the pilot made a combined rudder and foot right turn of 90° at which time the pilot throttled back in preparation for landing since the engine was not functioning properly and not producing climb. He then made a hard right turn using both rudder and feet. Upon reaching the original launch site the Flyer was too high and the cross wind was drifting the Flyer sideways. Therefore, full throttle was applied and another long run was made directly into the wind. Upon reaching the end of the runway, still at a full throttle setting of 3500 rpm, the pilot executed a magic flare turn* to the right. At this time the engine was not yielding full power and climb was marginal. The magic flare turn was utilized in order to conserve altitude. The turn was very slow and very wide sweeping running down almost one-half of the runway. When it was finally clear that the turn was much too large, the pilot then executed a 90° right rudder and foot turn. The engine performance continued to deteriorate as the Flyer headed downwind and back towards the ground observers at the launching site. Just prior to reaching the runway a 90° left rudder and foot turn was executed. At this point the pilot noted loss of altitude while turning. After completion of the turn the poor engine performance caused the machine to lose more altitude and to come down and

*A magic flare turn is accomplished by pulling down on one of the numerous riser lines so as to provide an aileron type effect.

touch the ground. At this point the pilot used foot controls to increase wing angle of attack which caused the Flyer to take off again into the air and to fly past the observers and to continue downwind. The pilot made a low altitude (approximately 20 ft.) hard 360° left turn using rudder and foot controls to avoid obstacles. Heading back towards the landing site, the pilot then made a 90° right turn and throttled back for the landing approach. Upon touchdown, the pilot applied full power and flare and again lifted the Flyer off the ground. Because this attempted take-off was cross wind and moving towards the hanger area, the pilot then cut the engine and applied full flaps to deflate the Parafoil. After the test flight it was found that the engine heat intake had been wired open thus reducing the engine's cool air supply. This probably accounts for the poor engine performance.

C. Brief Description of Flight #3 on 11 July 1974 (Figs. 23-29)

Flight #3 was programmed as a clean up flight to accomplish those items missed in the previous two flights, such as right rudder turns, straight flight on camera line, gliding flight, and full power climb out after gliding flight. Particular attention was placed on rudder turns with minimal use of foot controls.

The tow take-off and release were clean, followed by a good sustained climb straight into the wind. The pilot's feet were off the wing controls after launch. The first two upwind turns were rudder turns of 90° to the right. The subsequent downwind flight was centered on the two phototheodolite stations and was followed by a rudder turn of 90°, immediately followed by another right rudder turn of 90°. The subsequent upwind flight was straight and steady with no controlling of any kind. Once upwind, two 90° right rudder turns were made. On the subsequent straight downwind flight a smoke bomb mounted on the test vehicle was ignited. Again a 90° right cross wind rudder turn was made, immediately followed by a hard right rudder 90° turn into the wind. The subsequent upwind flight was steady at full power with no controlling whatsoever. At the mid-range point and at 165 seconds, the power was reduced. At first reduction of power it appeared to the pilot that the Flyer angle increased and the Flyer climbed. However, when the power was reduced to 1500 rpm and less, the Flyer went into a steady descending glide. No controlling of any kind was used during this glide. Application of full power was delayed until the last instant to obtain maximum data during gliding descent. Full power was then applied to avoid ground impact. Descent recovery and climbing flight were subsequently achieved. It was noted, however, that the engine was throwing oil and that the oil pressure had dropped. Accordingly, the pilot decided to return to the take-off site for a left turn descending landing approach. In order to accomplish this approach the pilot at 490 seconds made a 45° right rudder turn followed later by a 45° left rudder turn. At 520 seconds the pilot made a hard left rudder turn and proceeded downwind towards the launch site. The pilot then executed a

descending 180° left rudder and foot turn, thereby again lining up into the wind for a landing in the grass instead of on the concrete runway. At an altitude of 6 ft. the pilot cut the engine. (Figs. 25-29). Upon reducing the thrust, the Flyer pitched up to an angle of approximately 45° and the rear wheels touched down. Immediately thereafter, the front wheels slammed down and the rotational velocity plus the engine weight caused the front springs to bottom out. The nose beam and the tow line mechanism then dug into the ground causing the vehicle to nose over to an upside down position. The only damage to the Flyer was a broken magneto and a bent rudder. There was no damage to the pilot.

D. General Comments on the Wright Field Flights

The three test flights at Wright Field are considered to be representative of the general capabilities of the AeroFlyer concept. It was shown that the AeroFlyer can climb at angles of 1.35° to 5.37°, the latter is equivalent to an aircraft climbing at 586.6 ft/min while flying at 70 mph. The AeroFlyer was able to make both rudder and wing deflection turns to the right and to the left. Combined rudder and wing deflection turns were also able to achieve maneuverability. Rates of turn of 6 degrees per second and a radius of turns of 175 feet were readily demonstrated. Of particular importance was the demonstration of hands-off flight stability, both static and dynamic. The landings were all precise and easily controlled with little landing roll (less than 20 ft. was a typical landing roll distance). Two touch and go's were demonstrated. Direct take-off was achieved after the Wright Field tests with AeroFlyer 7 on 29 November 1974.

Therefore, in answer to question No. 1, it was demonstrated that the AeroFlyer can fly.

In the next section question No. 2 is answered by setting forth the data and performance obtained from the Wright Field flights.

VII. AEROFLYER FLIGHT PERFORMANCE

A. Velocity

The velocity of the AeroFlyer was reported by the pilot at various times during the three flights and it was computed from the phototheodolite data on flights #1 and #2. These velocity data from the phototheodolites are shown in Figs. 30-33.

The best extimate for the flight velocity for the AeroFlyer from these tests is approximately 42.5 ft/sec or 29 mph. This representative value was obtained from the phototheodolite data on the first and third flights. The velocity data obtained on the first half of each of these flights was emphasized but also certain of the second half data was used where maneuvering, turning or descending gliding flights were not involved. In both flights, the average into the wind and the average downwind values were obtained. Then these values were averaged and the resulting values for each flight were combined to yield the representative flight value. Figs. 34 and 35.

B. Turns

During the three test flights, a total of 43 turns* were carried out. Twenty turns (15 phototheodolite) were to the left and twenty-three (15 phototheodolite) turns to the right. There were 10 climbing turns (7 phototheodolite), 25 level turns (21 phototheodolite), and 8 descending turns (4 phototheodolite). One turn was precipitated by a gust or thermal. A summary of the various turns is given in Fig. 36, which also indicates the type of turn employed - rudder, wing deflection or foot controlled turns, and combined rudder and wing turns. It should be recalled that on the second flight the engine power was diminished due to the wrong engine air heat setting. Accordingly, it was necessary to use wing deflection or trim in order to produce the additional life required for sustained flight. These turns were also indicated.

It can be seen from the flight paths of each flight, Figs. 15, 19, and 23, that all types of turns were effective and that both gentle and very hard turns were accomplished. The pilot reported that both right and left turns were equally easily accomplished. This was true of both rudder and wing deflection turns. The rates of turn ranged from 1^{o}/s to 6^{o}/s. The minimum radius of turn was 175 ft.

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* A turn as defined here is an intentional pilot departure from straight flight.

C. Climbing Flight

One of the principal objectives of the flight test program was to obtain accurate data on climbing flight. As assessment of the climbing flight capability is of importance because it is an indication of the excess horspower which is available to the pilot above the horsepower required for level flight. As such, it is an indication of the safety of flight since a good climbing flight capability indicates that takeoff distances and times will be short and that the pilot can quickly climb away from obstacles.

Steady and sustained climbing flight was achieved at the outset of all flights and is recorded in the phototheodolite data for flights #1 and #3, Figs. 37 and 38. An average rate of climb of 1.07 ft/set was obtained during the first 256 seconds of flight #1 and a rate of .88 ft/sec was obtained during the first 171 seconds of flight #3. These average rates were achieved during straight flight, turning flight, and downwind flight. A nominal overall representative value of the rate of climb is, therefore, approximately 1.0 ft/sec or 60 ft/min.

Also, during these flights, higher values for rate of climb were obtained of 2.4 ft/sec for 31 sec, 3.2 ft/sec for 22 sec, and 4.0 ft/sec for 14 sec. These higher values are achieved primarily in straight flight and where increased trim and L/D is provided and where there is no controlling or turning of the Flyer.

D. Gliding Flight

Obtaining data on unpowered gliding flight was of importance since the rate of sink and the glide angle are fundamental aerodynamic quantities which provide estimates of the horsepower required to fly level and the overall aerodynamic efficiency of the complete AeroFlyer system, L/D. The gliding flight was accomplished by first flying directly into the wind and then throttling back and proceeding into a hands-off the controls free glide. These data are shown in Figs. 39, 40 and 46. The rate of sink is measured to be 11.98 ft/sec* and the lift-to-drag ratio to be 3.54.** These estimates may be open to question because of the short time, 14 sec, and short distance of the glide and because some engine power was still being applied. The pilot reported clean transition into glide, completely hands-off flight, and a clean transition into powered flight. The latter is confirmed

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*Univ of Dayton data reductions for $\dot{H}_{max}$ during 448-462 sec.
**Based on V=42.5 ft/sec. Note that Fig. 46 yields L/D $\approx$ 4.

in the associated velocity data, Fig. 46. Additional confirming flights must be carried out, using either phototheodolite data or on-board flight instrumentation to verify the above estimates of gliding performance.

E. Landings

The landing* on the first flight was soft and the landing roll was less than 20 ft. A shorter landing roll could have been accomplished if full flaring and early engine shut down had been utilized.

The landing on the second flight was excellent. Immediately following soft touchdown the pilot applied full power in order to demonstrate take-off. While all four wheels lifted off the ground for less than 1 second, the light cross wind and area safety concerns made an immediate landing advisable. This landing was easily accomplished.

The landing on the third flight was not nominal, as described in a previous section**. Both pilot error (too early and abrupt engine shut down) and terrain inadequacy were involved.

In general, it has been demonstrated that the AeroFlyer may be landed softly, with accuracy and with short landing roll.

F. Lift Coefficient

The lift coefficient acting on the AeroFlyer may be determined from the estimated flight velocity. In the case of level flight we may write

$$L = C_L \tfrac{1}{2}\rho V^2 A = W$$

or

$$C_L = \frac{2W}{\rho A V^2} = \frac{2 \times 579.4}{.002211 \times 396.4 \times 42.5^2}^{***} = .7321$$

Drag Coefficient

Since we were able to determine the lift to drag ratio directly from the gliding flight, we may now compute the total drag coefficient as

$$C_D = \frac{C_L}{L/D} = \frac{.7321}{3.54} = .2068$$

*Landing R/S $\approx$ 2.86 ft/sec and $\gamma = 3.84^{\circ}$

**Landing R/S $\approx$ 3.03 ft/sec and $\gamma = 4.07^{\circ}$. Also see Figs. 39&40.

***Measured values.

G. Components of Drag

The total drag that is acting on the AeroFlyer in flight is composed of two parts, $C_D = C_{D_p} + C_{D_i}$. The first part is due to parasite effects and the second part is due to lift. The parasite part arises from both the profile drag and the residual drag. The second part arises directly from the lift required to fly and this induced drag may be approximately estimated from[23]

$$C_{Di} = \frac{C_L^2}{\pi R e} = \frac{AC_L^2}{\pi e b^2} = \frac{396.4 \times .7321^2}{\pi \times .855^* \times 28.75^2} = .0956$$

Since we were able to previously determine the value of the total drag coefficient, we may use this estimated value of the induced drag to determine the parasite drag as

$$C_{Dp} = C_D - C_{Di} = .2068 - .0956 = .1112$$

Thus, these estimates suggest that the parasite drag is 53.7% of the total drag and that the induced drag is 46.2%**

The low value of induced drag has been helped by the large span of the wing and by the value for the AeroFlyer efficiency factor, e. However, it has been hurt by the large value of C_L and also by the large wing area.

It is also clear that the parasite drag should be and can be reduced considerably. The profile drag, the line drag, and the fuselage drag can all be greatly reduced by reducing the projected areas and by streamlining.

It should be remembered that the basic objectives of this program were to demonstrate flight with existing equipment and to obtain performance data. A follow-on effort could be directed at demonstrating more efficient flight.

H. Horsepower for Flights

The horsepower required for level flight may be estimated from the flight data from

$$HP_o = \frac{VW}{L/D\ 550} = \frac{42.5 \times 579.5}{3.54 \times 550} = 12.65$$

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*23

**Since $HP_R = \frac{VD}{550}$, the total horsepower required to fly level is comprised of 53.7% overcoming parasite drag and 46.2% resulting from the lift required to fly.

The nominal representative excess horsepower may be estimated from

$$\Delta HP = \frac{R/C \times W}{550} = \frac{1.0 \times 579.5}{550} = 1.054 \qquad \gamma = \tan^{-1} \frac{1.0}{42.5} = 1.35^{o}$$

The total nominal horsepower available, therefore, is

$$HP_A = HP_o + HP = 12.65 + 1.054 = 13.70$$

The maximum excess horsepower is estimated to be*

$$\Delta HP_{max} = \frac{4.0 \times 579.5}{550} = 4.214 \qquad \gamma = \tan^{-1} \frac{4.0}{42.5} = 5.37^{o}$$

The total maximum horsepower available is, thus, estimated to be

$$HP_{A_{max}} = HP_o + HP_{max} = 12.65 + 4.214 = 16.86$$

assuming an estimated propeller efficiency of 50% at 3500 rpm, the estimated engine horsepower is 33.7.

While this value may seem low for this engine, it should be recalled that it has survived many crashes, many broken propellers, the main shaft is bent, the engine throws oil, and these flights were on very hot days.

Measurements of the static thrust are given in Fig. 42 of 250# at 3500 rpm. The flight thrust is estimated from

$$T_F = \frac{550\ HP_A}{V} = \frac{550 \times 16.86}{42.5} = 218.18$$

The actual thrust at flight velocity is known to be diminished from the static thrust due to the reduced angle of attack of the blade elements. Thus, this reduction in thrust of 12.7% is considered within reason, Fig. 42 .

I. AeroFlyer Trim

The flight trim of the Parafoil may be estimated from the value of C_L and from the wind tunnel data[1,2] to be 7° at an L/D of 3.661. The sequence still photographs, the documentary movies and the phototheodolite data indicate a low value of the Parafoil's trim angle of attack of 5° as compared to the more optimum trim value of 10° which yields a C_L of .828 and L/D of 3.680. Fig. 41 .

*Based on the best rate of climb obtained.

J. More Optimum Flight Performance

These various test data suggest that if the Parafoil had been retrimmed to 10° and the Flyer retrimmed to 15° then the following AeroFlyer flight performance values could have been obtained at Wright Field:

$$V = V_0\sqrt{\frac{C_{L_0}}{C_L}} = 42.5\sqrt{\frac{.7321}{.828}} = 39.96 \text{ ft/sec, } 27.24 \text{ mph}$$

$$HP_A{}^* = 16.86\ (1+.05) = 17.70$$

$$HP_0 = \frac{39.96 \times 579.5}{3.66 \times 550} = 11.50$$

$$\Delta HP_{max} = 6.2$$

$$R/C = \frac{550 \times 6.2}{579.5} = 5.88 \text{ ft/sec, } 353.0 \text{ fpm}$$

$$\gamma_c = 8.37^\circ$$

If the excess weight of instruments, tank, large wheels, heavy landing gears had all been reduced, the estimated AeroFlyer flight performance could have been

$$V = V_0\sqrt{\frac{525}{579.5}} = 38.03 \text{ ft/sec, } 25.9 \text{ mph}$$

$$HP_0 = 10.94 \qquad \Delta HP_{max} = 6.75$$

$$R/C = 7.07 \text{ ft/sec, } 424.6 \text{ fpm} \qquad \gamma_c = 10.5^\circ$$

A new 2000 cc VW engine is now available to A-E-R-O, having 60 hp. Using this engine the following AeroFlyer performance would be obtained:

$$V = 38.03 \text{ ft/sec, } 25.9 \text{ mph}$$

$$HP_0 = 10.94 \qquad \Delta HP_{max} = 19.06$$

$$R/C = \frac{550 \times 19.06}{525} = 19.96 \text{ ft/sec, } 1198 \text{ fpm}$$

$$\gamma_c = 27.7^\circ$$

If the 200 ft^2 Aspect Ratio 3.0 Parafoil is used, which is also available, the AeroFlyer flight performance would be

$$V = 49.7 \text{ ft/sec, } 33.8 \text{ mph}$$

$$HP_0 = 11.0 \qquad \Delta HP_{max} = 18.9$$

$$R/C = 19.9 \text{ ft/sec, } 1198 \text{ fpm}$$

$$\gamma_c = 21.8^\circ$$

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*Provides 5% more thrust obtained by using θ_F = 15 at L/D = 3.

If we are satisfied with a rate of climb of 300 fpm and the same velocity we would have a surplus payload of 473.3#. If we use this payload for fuel, we can compute a flight range for the AeroFlyer of 653 miles.

K. Comparison with AeroFlyer Theory

Various calculations for AeroFlyer performance are given in U. S. Air Force Flight Dynamics Laboratory Reports, Refs. 1 and 2. In Fig. 43 , from this report, the flight measured horsepower and L/D are plotted. The measured flight velocity is also plotted in Fig. 45 . These curves also indicate the AeroFlyer performance gains that can be achieved by improvements in L/D, wing loading, power loading, lift coefficient, et. al.

The Wright Field test flights, therefore, have confirmed the previous performance predictions for the AeroFlyer. The previous report may, therefore, be used to obtain initial estimates of AeroFlyer systems ranging in weight from 10# to 10,000#.

L. Phugoid Motion

The velocity data from the phototheodolite cameras shows a short period oscillation. These oscillations also appeared in the previous Hang Gliding tests reported in Ref. 9 . The oscillation occuring immediately following the gliding portion of flight #3 is shown in Fig. 93 . This period is estimated to be approximately 8 sec.

The phugoid period may be calculated to be[21]

$$T = \frac{\pi\sqrt{2}V}{g} = 5.86 \text{ sec}$$

$$T^* = .178\ V = 7.565 \text{ sec}$$

Previous Hang Gliding flight tests** at Wright Field yielded T_{ex} = 6 sec, T = 4.48 sec, and T* = 5.78 sec.

Therefore, the short period oscillations observed in the Parafoil Hang Gliding tests and the AeroFlyer tests at Wright Field are found to be a Phugoid Motion.

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* Ref. 22, p. 402

** 18 Aug 1969, WP-69-608

VIII. DIRECT TAKE-OFF

Direct take-off from the ground has been attempted on several occasions (Flight #67 and Flight #68). While lift off was achieved in each case, the results were not conclusive.

The review meeting held at Wright Field in the Fall of 1974, following the flight tests, confirmed that the flights had achieved most of the general objectives set forth with the exception of self powered take-off and climbing to 1000 ft. It was also decided that no additional tests would be carried out at Wright Field because of safety considerations.

Direct take-off flights were, therefore, conducted at the test site at Goshen, Indiana, utilizing AeroFlyer 7 which had been constructed and prepared for these flight tests.

On flight 79 AeroFlyer 7, with its engine idling and with the Parafoil laid out on the ground below it, was attached to the tow car by a tow line 60 ft. long. During erection of the Parafoil the car moved at approximately 5 mph and two wing men initially held the Foil's leading edge open to the wind. Immediately the Foil came up overhead and flew like a kite attached to the AeroFlyer. After inspection of the lines by the pilot, he released the tow line and applied full power. The Flyer moved along the ground for a short distance and lift off occurred. Immediately after lift off the AeroFlyer turned to the left due to engine and propeller torque. The small rudder, while somewhat diminishing the left turn, was not truly effective. Further, the loose engine power belt greatly reduced the effective thrust. As a result of the low thrust and the extensive wing warping required for control, an altitude of only 10 ft. or so was attained. Furthermore, this low altitude, the inability to fly straight, and the imminent danger of obstacles directly ahead, led to an early cross wind landing which was otherwise uneventful.

Following the installation of a larger rudder, the tightening of the engine power belt and an engine rpm and power check, a second direct take-off flight was planned for on Thanksgiving Day 1974. Thus, on flight 80 on 29 November 1974 the Parafoil erection procedure was identical to that of the previous flight. The take-off distance was approximately 100 ft. The take-off was easy and clean. The climb itself was fast and steep. The estimated rate of climb was 10 ft/sec and the climb angle was observed by the pilot and the ground personnel to be steep. An estimated altitude of approximately 1000 ft. was reached. It had not been the pilot's intention to fly so high on the first flight. However, the natural vibration of the fuselage caused the throttle to work itself into the full power position each time it was verniered back. When this was finally realized by the pilot, the climb was checked and steady level flight was achieved by holding the throttle at the desired setting. Both right and left rudder turns were easily accomplished

and the remaining flight was level and smooth. The pilot had no problem in circling the field and descending to a controlled landing. Due to the wide foot print of both the front wheels and the rear wheels there was complete AeroFlyer stability on landing with absolutely no tendency to roll or tumble. The flight was a complete success.

Unfortunately, the surprise of the pilot in achieving this success of direct take-off caused him to ignore the on-board instrumentation. In order to obtain accurate performance data on take-off, climb, free glide, and maneuverability, F7 must be further flight tested.

The estimated and calculated flight performance of AeroFlyer 7 is,

$$V = 42.5\sqrt{\frac{481}{579.5}} = 38.7 \text{ ft/sec, } 26.4 \text{ mph}$$

$$HP_o = \frac{38.7 \times 481}{3.54 \times 550} = 9.56$$

The measurement of static thrust is found to be 215# and thus, the total horsepower available is given by

$$HP_A = \frac{TV}{550} = \frac{.873 \times 215 \times 38.7}{550} = 13.20$$

$$\Delta HP = HP_A - HP_o = 13.2 - 9.56 = 3.647$$

$$R/C = \frac{550 \times 3.647}{481} = 4.170 \text{ ft/sec, } 250.2 \text{ fpm}$$

$$\gamma_c = 6.15^o$$

By optimizing Parafoil and Flyer trim,

$$V = 39.96\sqrt{\frac{481}{579.5}} = 36.4 \text{ ft/sec, } 24.8 \text{ mph}$$

$$HP_o = 9.56 \times \frac{36.4}{38.7}(1 - .05) = 8.99 - .449 = 8.54$$

$$\Delta HP = 13.2 - 8.54 = 4.66$$

$$R/C = 5.32 \text{ ft/sec, } 319.7 \text{ fpm}$$

$$\gamma_c = 8.33^o$$

IX. CONCLUDING REMARKS

The 80 flights of the AeroFlyer, and particularly the three Wright Field flights of F5 and the Thanksgiving flight of F7, have demonstrated that the AeroFlyer can fly. It can also take off, fly with hands-off static and dynamic stability, be maneuvered easily and can land at a predetermined point with little ground roll (on the order of 20 ft.). *

For AeroFlyer 5 the nominal flight velocity is 42.5 ft/sec and the horsepower required for level flight is 12.6. For AeroFlyer 7 the estimated flight velocity is 38.7 ft/sec and the estimated horsepower required for level flight is 9.6.

By optimizing the trim of the Parafoil, the AeroFlyer 5 should be able to achieve a flight velocity of 40 ft/sec and a horsepower required for level flight of 11.5. AeroFlyer 7 should be able to achieve a flight velocity of 36.4 ft/sec and a horsepower of 8.5. Additional improvements may be obtained by using current Parafoil designs and by drag optimization.

The predictions of AeroFlyer flight performance are in excellent agreement with the flight data and, thus, the predictions for AeroFlyer system weights from 10# to 10,000# should be valid and useful in considering various AeroFlyer applications over a wide spectrum from pilot ejection seat flight to RPV low speed flight and recovery. Many missions now achieved by helicopters may be carried out more effectively and at much less cost using the AeroFlyer.

Additional flight tests and designs are recommended in order to obtain a wider spectrum of flight performance including higher wing loadings, greater velocity, and true landing flare with no roll.

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*AeroFlyer F5 achieved the first direct take-off from the ground at Cal Poly on 12 March 1976 with repeated direct take-offs on 29 April, 23 June, and 29 June 1976. An altitude in excess of 500 ft. was achieved. AeroFlyer F7 demonstrated direct take-off at Cal Poly on 10 June 1976 and achieved an altitude in excess of 1,000 ft.

No.	Type	Flyer	Pilot	Date	Location	Description
1	G	F0	N	1967	ND	Tow ascension, release, and glide
2	G	F0	N	1967	ND	Tow ascension, release, and glide
3	G	F0	N	1967	ND	Tow ascension, release, and glide
4	G	F0	N	1967	ND	Tow ascension, release, and glide
5	G	F0	N	1967	ND	Tow ascension, release, and glide
6	G	F0	N	1967	ND	Tow ascension, release, and glide
7	G	F0	N	1967	ND	Tow ascension, release, and glide
8	G	F0	F	1968	ND	Tow ascension, release, and glide
9	G	F0	F	1968	ND	Tow ascension, release, and glide
10	G	F0	F	1968	Fair	Tow ascension, release, and glide
11	P	F1	F	Summer 1968	Goshen	First attempt at powered flight. Very high α_T
12	P	F1	F	Summer 1968	Goshen	First attempt at powered flight. Very high α_T
13	P	F1	F	Summer 1968	Goshen	First attempt at powered flight. Bent landing gear.
14	G	F2	H	Summer 1971	ND	Tow ascension, release, and glide
15	G	F2	H	1971	Sportsmans	Tow ascension, release, and glide
16	P	F2	F	24 Aug 71	Goshen	Straight and slow descending
17	P	F2	F	24 Aug 71	Goshen	Straight and slow sescending

Figure 1 List of AeroFlyer Flights

No.	Type	Flyer	Pilot	Date	Location	Description
18	P	F2	F	24 Aug 71	Goshen	Straight and slow descending
19	P	F2	F	24 Aug 71	Goshen	Straight and slow descending
20	P	F2	F	24 Aug 71	Goshen	Bad roll over during tow, F2 destroyed
21	G	F3	T	1971	Goshen	Ascension and glide
22	G	F3	T	1971	Goshen	Ascension and glide
23	G	F3	T	1971	Goshen	Ascension and glide
24	P	F3	T	11 Dec 71	Goshen	Right turning and descending
25	P	F3	T	11 Dec 71	Goshen	Right turning and descending
26	P	F3	T	11 Dec 71	Goshen	Right turning and level
27	P	F3	T	12 Dec 71	Goshen	12 miles in level continuous right turns
28	P	F3	T	27 Apr 72	Goshen	AF demonstration, right level turns
29	G	F4	M	7 Oct 72	Goshen	Tow, ascend, glide. (NO stop order)
30	P	F4	N	5 Nov 72	Goshen	Large nose up-throttle closed itself-large α_T - descending
31	P	F4	N	11 Nov 72	Goshen	Line snagged-slow descent-cleared fence-large α_T
32	P	F4	N	11 Nov 72	Goshen	Almost level-missed post-large α_T
33	P	F4	F	11 Nov 72	Goshen	5000 RPM-slow descent-power landing
34	P	F4	N	24 Nov 72	Goshen	Almost level-over right corn field
35	P	F4	N	24 Nov 72	Goshen	Turn over on tow-no damage
36	P	F4	N	24 Nov 72	Goshen	Almost level-control tests-excellent power landing
37	P	F4	N	2 Dec 72	Goshen	Almost level-high speed take-off over pit-turns
38	P	F4	N	2 Dec 72	Goshen	Roll over on tow-bent bar-flights stopped

Figure 1 (Continued)

No.	Type	Flyer	Pilot	Date	Location	Description
39	P	F4	N	31 May 73	Goshen	Straight and slow descending. Climb.
40	P	F4	N	31 May 73	Goshen	Straight and slow descending.
41	P	F5	N	10 Jun 73	Goshen	Large nose up and descend.
42	P	F5	N	10 Jun 73	Goshen	Large nose up and descend.
43	P	F5	F	10 Jun 73	Goshen	Roll over during ground tow. Broke prop original
44	P	F4	N	22 Jun 73	Goshen	Turn over...
45	P	F4	N	22 Jun 73	Goshen	Straight and slow descending.
46	P	F4	N	Jul 73	Goshen	Straight and slow descending.
47	P	F4	N	Jul 73	Goshen	Straight and slow descending w/turns.
48	P	F4	N	Jul 73	Goshen	Straight and slow descending w/turns
49	P	F4	N	Jul 73	Goshen	Straight and slow descending w/turns.
50	P	F4	N	15 Aug 73	Goshen	CBS #1 straight and descending.
51	P	F4	N	15 Aug 73	Goshen	CBS #2 straight, left turn, landing.
52	P	F4	N	15 Aug 73	Goshen	CBS #3 right turn over TV crew.
53	P	F4	N	15 Aug 73	Goshen	CBS #4 full and wide 360 with landing.
54	P	F5	N	15 Sep 73	Goshen	S- N hard right turn, low over field & fence.
55	P	F5	N	15 Sep 73	Goshen	S- N right turn, left turns, landing O.K.
56	P	F5	F	15 Sep 73	Goshen	Roll over during ground tow. Broke prop.
57	P	F5	N	23 Sep 73	Goshen	E-W hard right turn, landing immediate.
58	P	F5	N	23 Sep 73	Goshen	E-W straight west, hit large gust, marginal landing at end of runway.

Figure 1 (Continued)

No.	Type	Flyer	Pilot	Date	Location	Description
59	P	F5	N	23 Sep 73	Goshen	E-W straight west, good turns, very bad landing. Broke frame, prop, and pelvis.
60	P	F5	N	20 Oct 73	Goshen	Straight, ascend, turns, O.K. landing.
61	P	F5	N	4 Nov 73	Goshen	Straight, ascend, turns, O.K. landing. 35 mph, added trim crank, 4 min.
62	P	F5	N	4 Nov 73	Goshen	Straight, ascend, turns, O.K. landing. 13 turns, trim.
63	P	F5	N	4 Nov 73	Goshen	Straight, ascend, turns, O.K. landing. No trim, no feet, oil smoke. 35 mph, 3500 rpm over plane.
64	P	F5	N	4 Nov 73	Goshen	Straight, ascend, turns, O.K. landing. 35 mph$^+$, no feet, 10 turns, 6 min.
65	P	F5	N	10 Nov 73	Goshen	Thumbs up, excellent flight. High α_T, weird landing, broke prop, but 35 mph, ???
66	P	F4 360	N	11 Nov 73	Goshen	Left turn during tow - no climb - pull front risers - good landing.
67	P	F4 360	N	17 Nov 73	Goshen	Direct take-off attempt. Many small lift-offs. α_T reduced.
68	P	F4 400	N	17 Nov 73	Goshen	Direct take-off attempt. Roll over, broke prop.
69	P	F4	N	23 Nov 73	Goshen	Dive, left, corn field landing. Small α_T and poor prop.
70	P	F4	N	23 Nov 73	Goshen	Left turn, almost level, cornfield landing. Still poor prop.
71	P	F5	N	1 Dec 73	Goshen	First perfect flight. Climb et al... Landed on Charlie front wheel came off.
72	P	F5	N	17 Dec 73	Goshen	Demo for AF/CBS. Perfect flight... 22 knots;- 3300 - 2000 RPM

Figure 1 (Continued)

No.	Type	Flyer	Pilot	Date	Location	Description
73	P	F5	N	21 May 74	Goshen	Good flight. Small climb. Wheel off on landing. Tumble over. Broke prop.
74	P	F6	N	May 74	Goshen	Bent frame on take off.
75	P	F6	N	2 Jun 74	Goshen	Good level flight- turns left and right - climb was marginal - excellent landing.
76	P	F5	N	9 Jul 74	Wright	Good climb turns - landing
77*	P	F5	N	10 Jul 74	Wright	Good initial climb - engine heat - various maneuvers over field - two touch and goes - press coverage.
78*	P	F5	N	11 Jul 74	Wright	Good climb - turns - glide - landing tumble
79*	P	F7	N	27 Oct 74	Goshen	Very short tow - direct take-off - alt 10' left turn - no rudder - almost hit a/c - good cross wind landing.
80	P	F7	N	29 Nov 74	Goshen	Very short tow direct take-off - (100' -) Steep climb 1,000' - throttle kept velocity to full open - excellent turns - level at ½ power - perfect landing.

*Flight number 77, 78, and 79 at Wright Field are also referred to as Flight Number 1, 2, and 3 throughout the report.

Figure 1 (Continued)

NOMENCLATURE

Type	G	=	Glider Flight (No engine)
	P	=	Powered Flight
AeroFlyer	F0	=	Three wheeled glider cart
	F1	=	Modified Benson-Gyro
	F2	=	VW powered tractor (3-wheel)
	F3	=	Rockwell powered pusher (3-wheel)
	F4	=	Rockwell powered tractor (4-wheel)
	F5	=	VW powered tractor (4-wheel)
Pilot	N	=	Dr. John D. Nicolaides (55 flights)
	F	=	Lowell Farrand (14 flights)
	T	=	Edward Travares (8 flights)
	H	=	Michael Higgins (2 flights)
	M	=	Pete McCabe (1 flight)
Location	ND	=	University of Notre Dame Athletic Field
	Fair	=	Sturgis Michigan Fair Grounds
	Goshen	=	Goshen Indiana Municipal Airport
	Sportsman's	=	Mishawaka Indiana Sportsman's Air Park
	Wright	=	Wright Field, Ohio

Figure 1 (Continued)

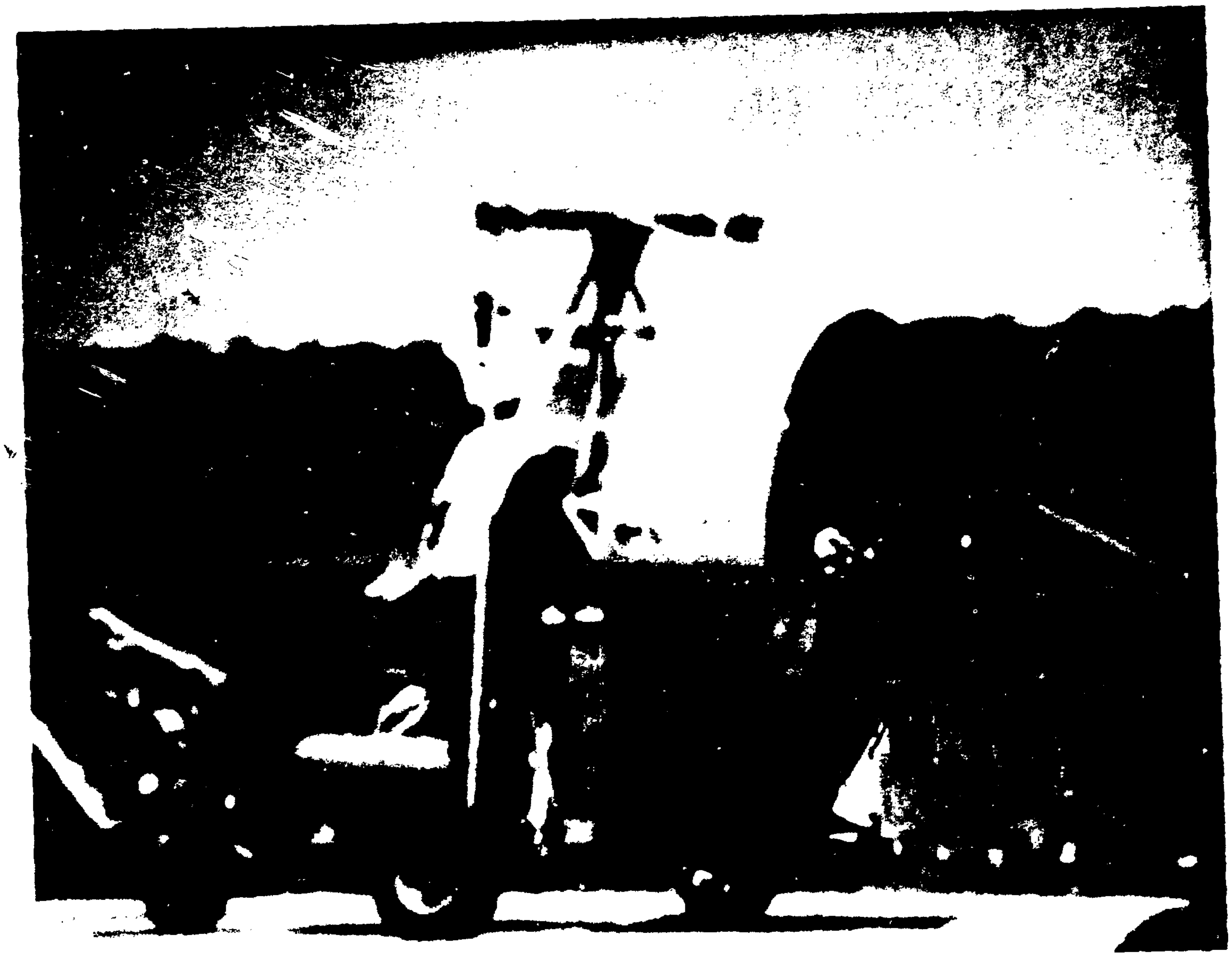


Figure 2 First AeroFlyer, F1

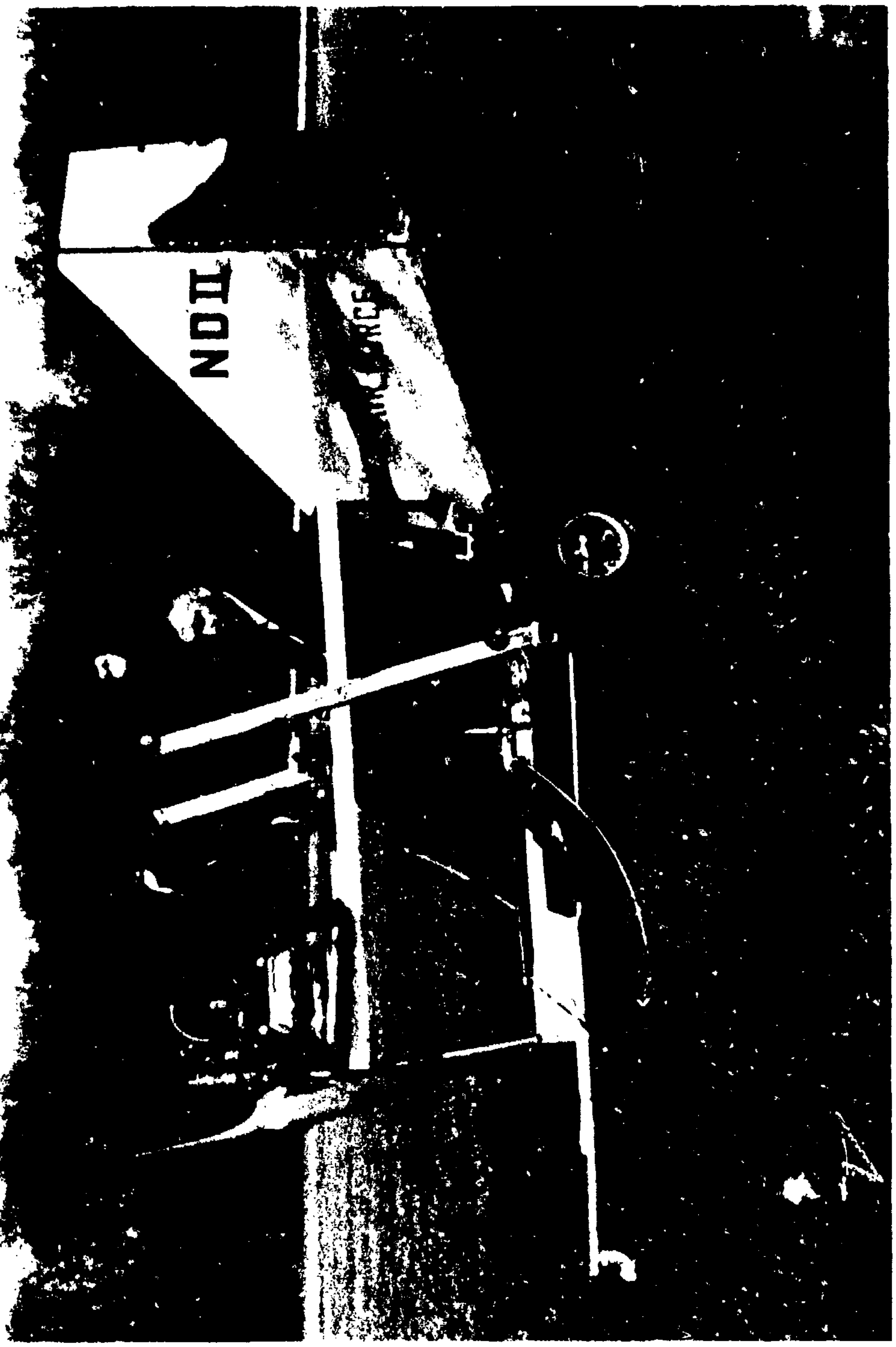


Figure 3 AeroFlyer, F2

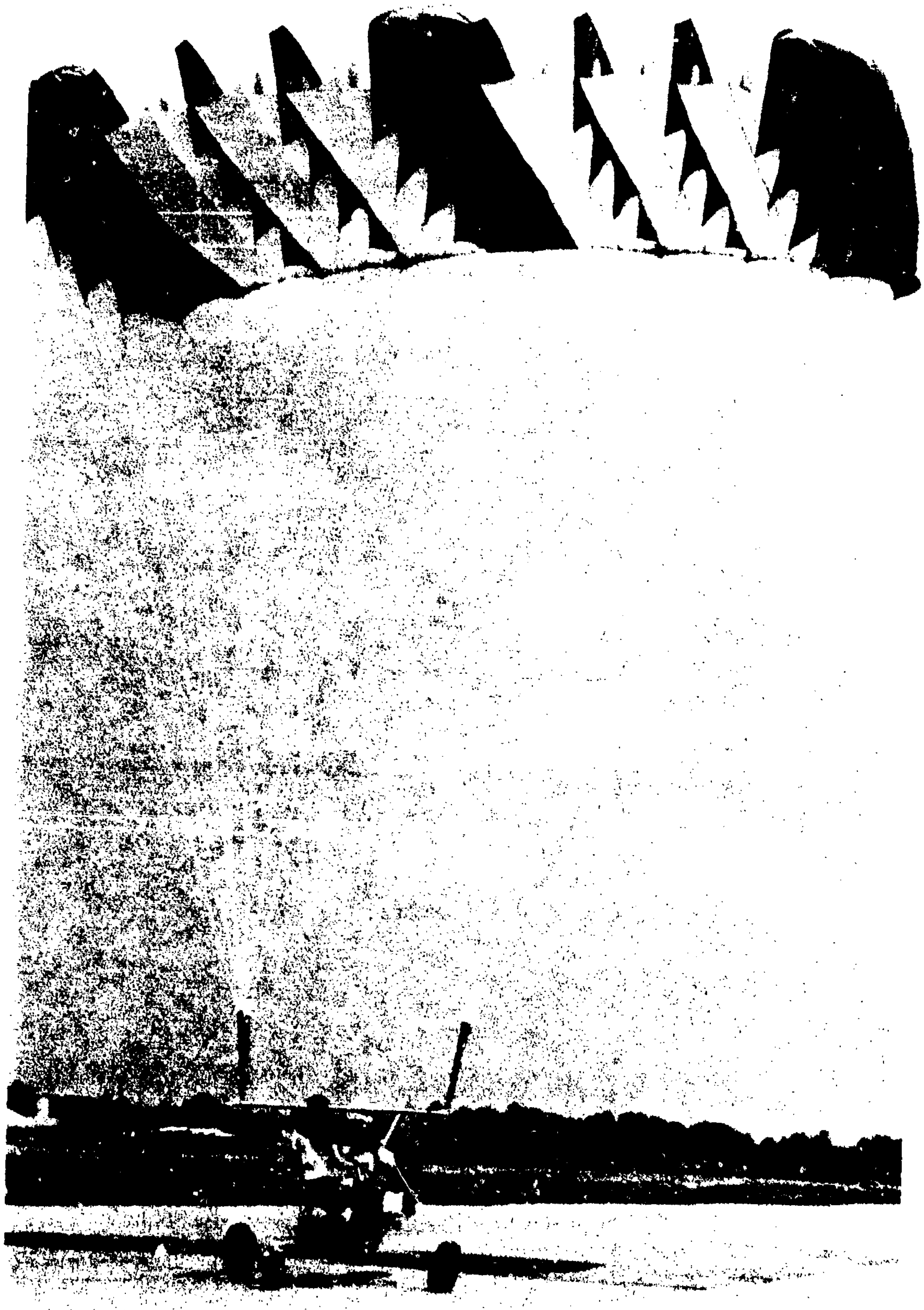


Figure 4 AeroFlyer, F2, Landing

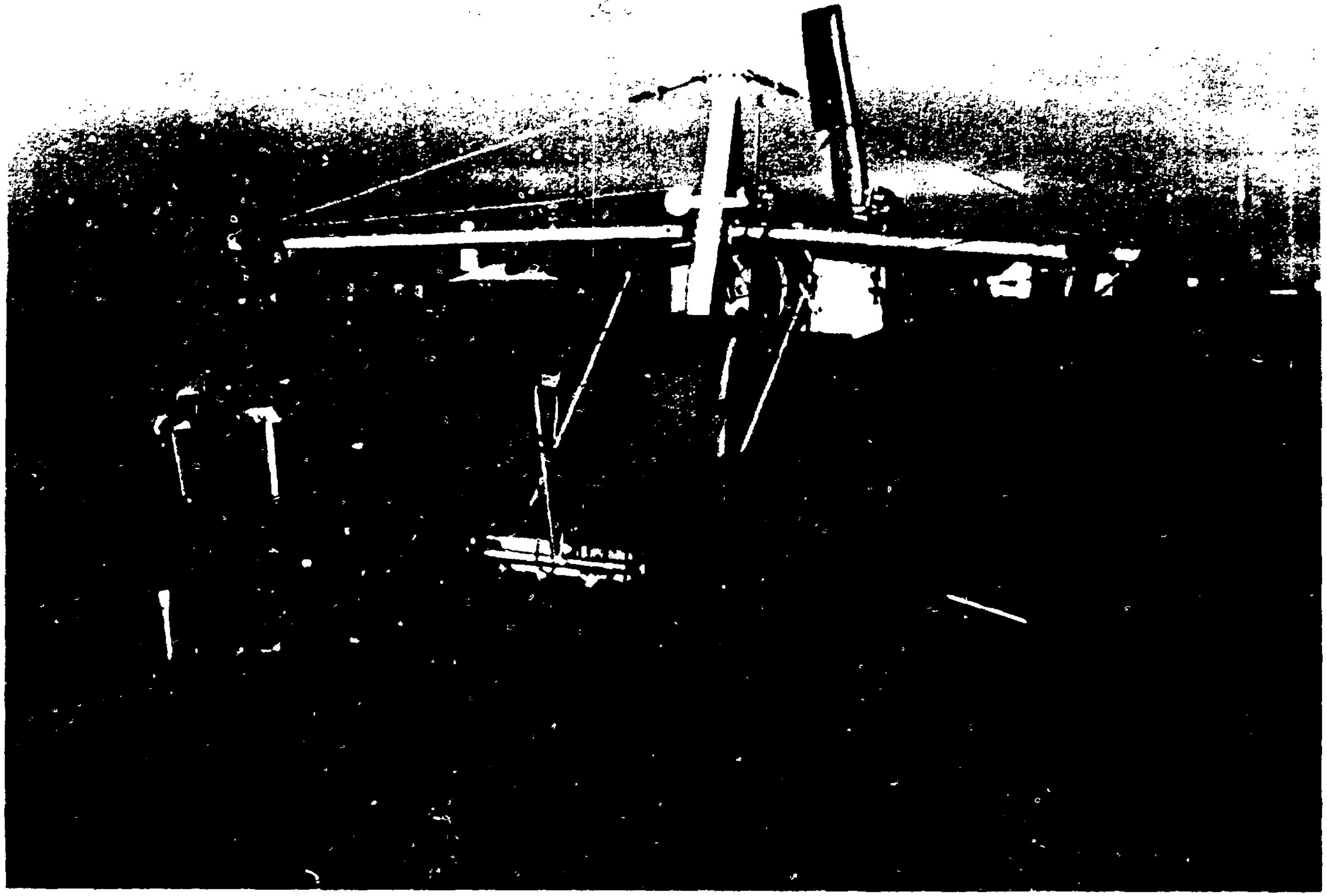


Figure 5 AeroFlyer F3

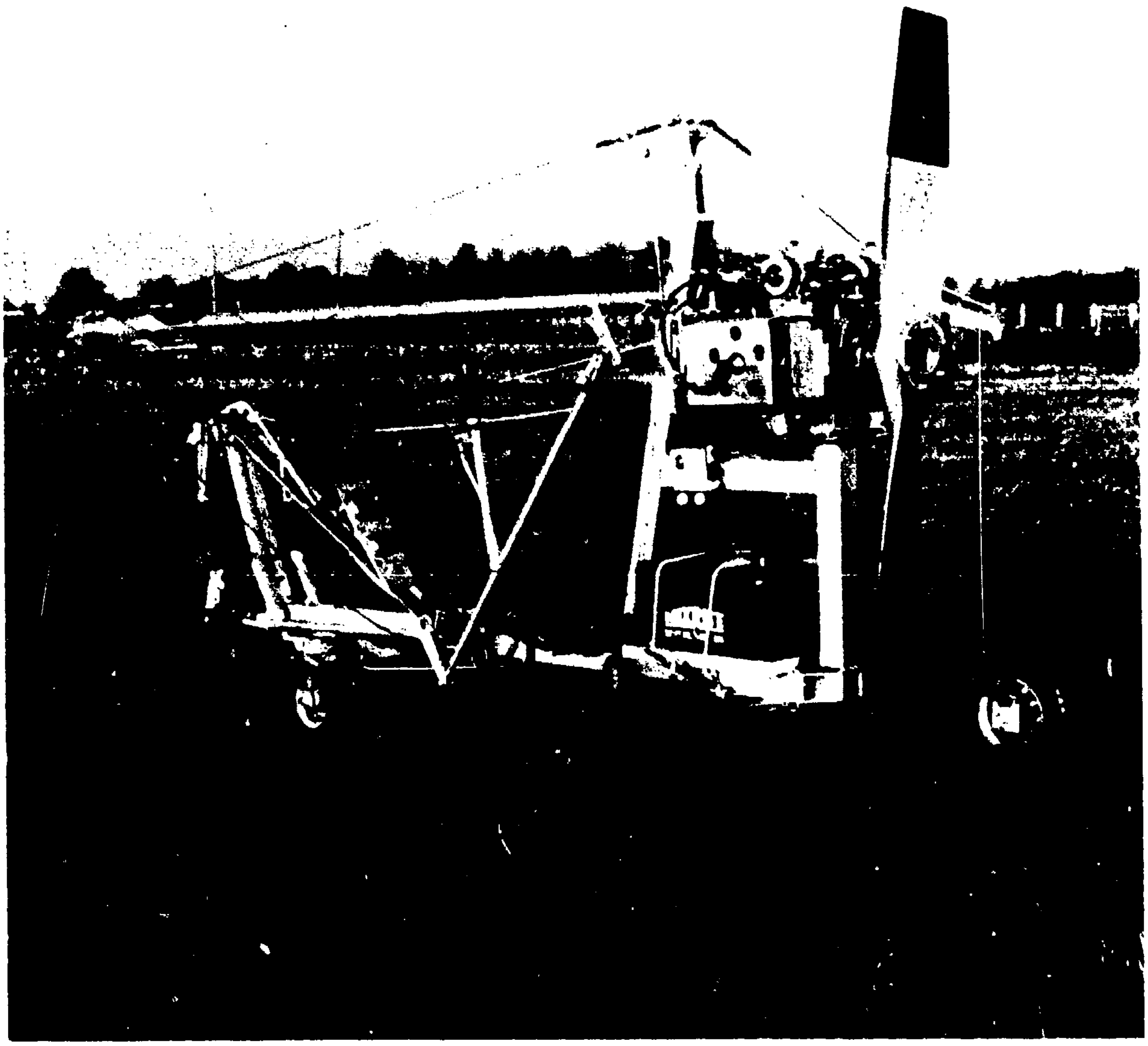


Figure 6   AeroFlyer, F3

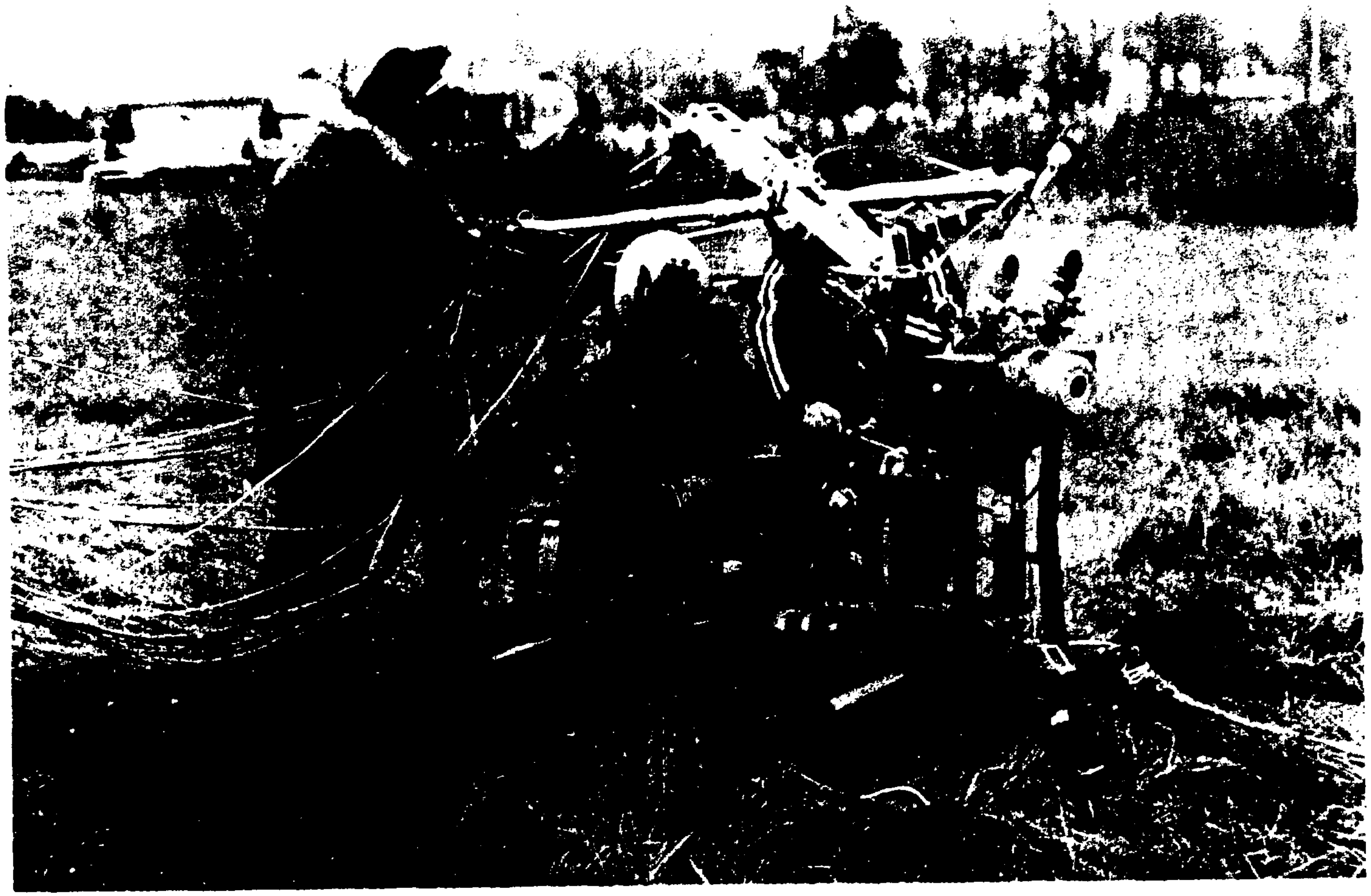


Figure 7   AeroFlyer, F4, During Engine Run Up Prior to Flight Test

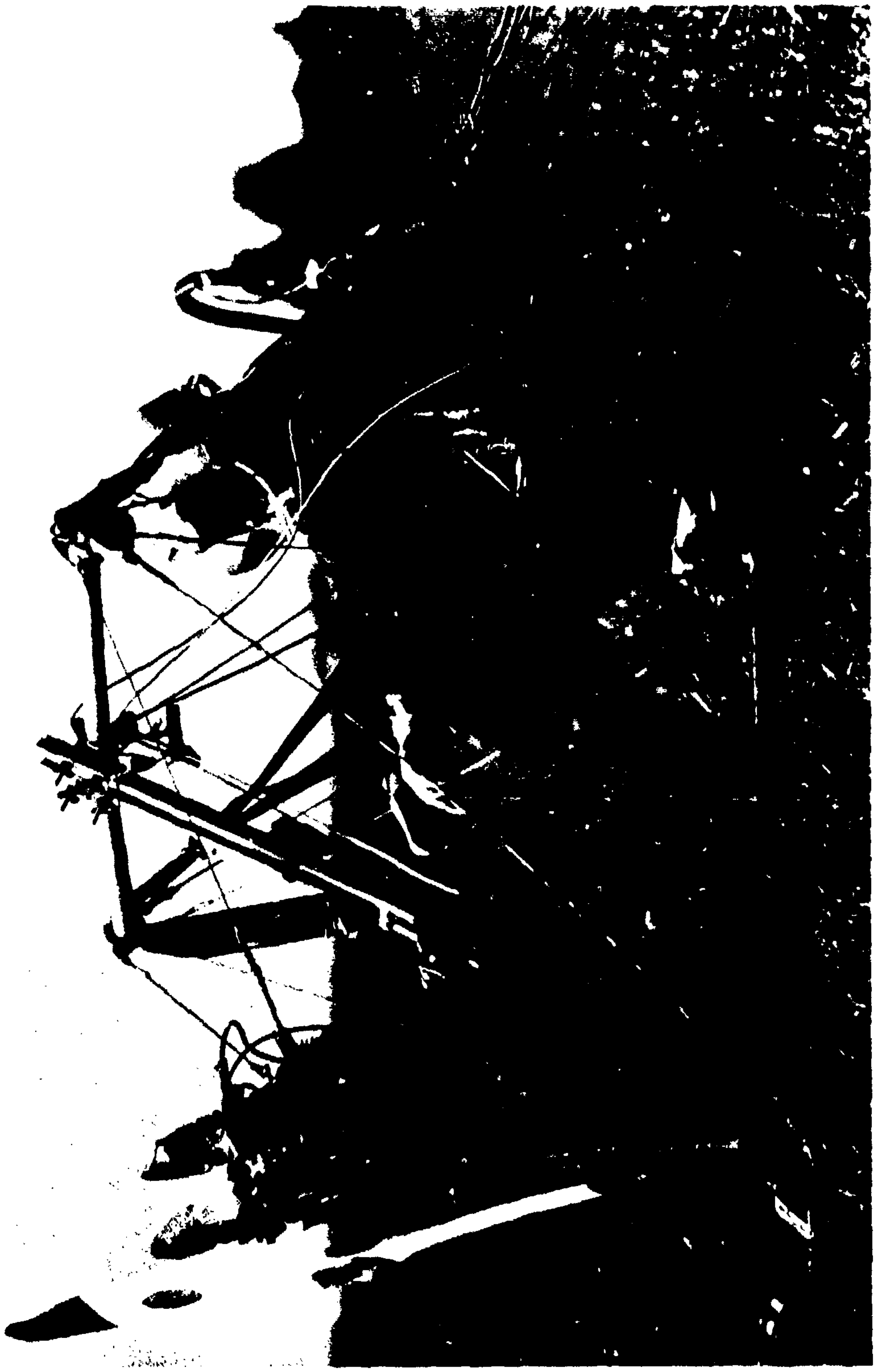


Figure 8 AeroFlyer, F4 (light), Prior to Flight Tests

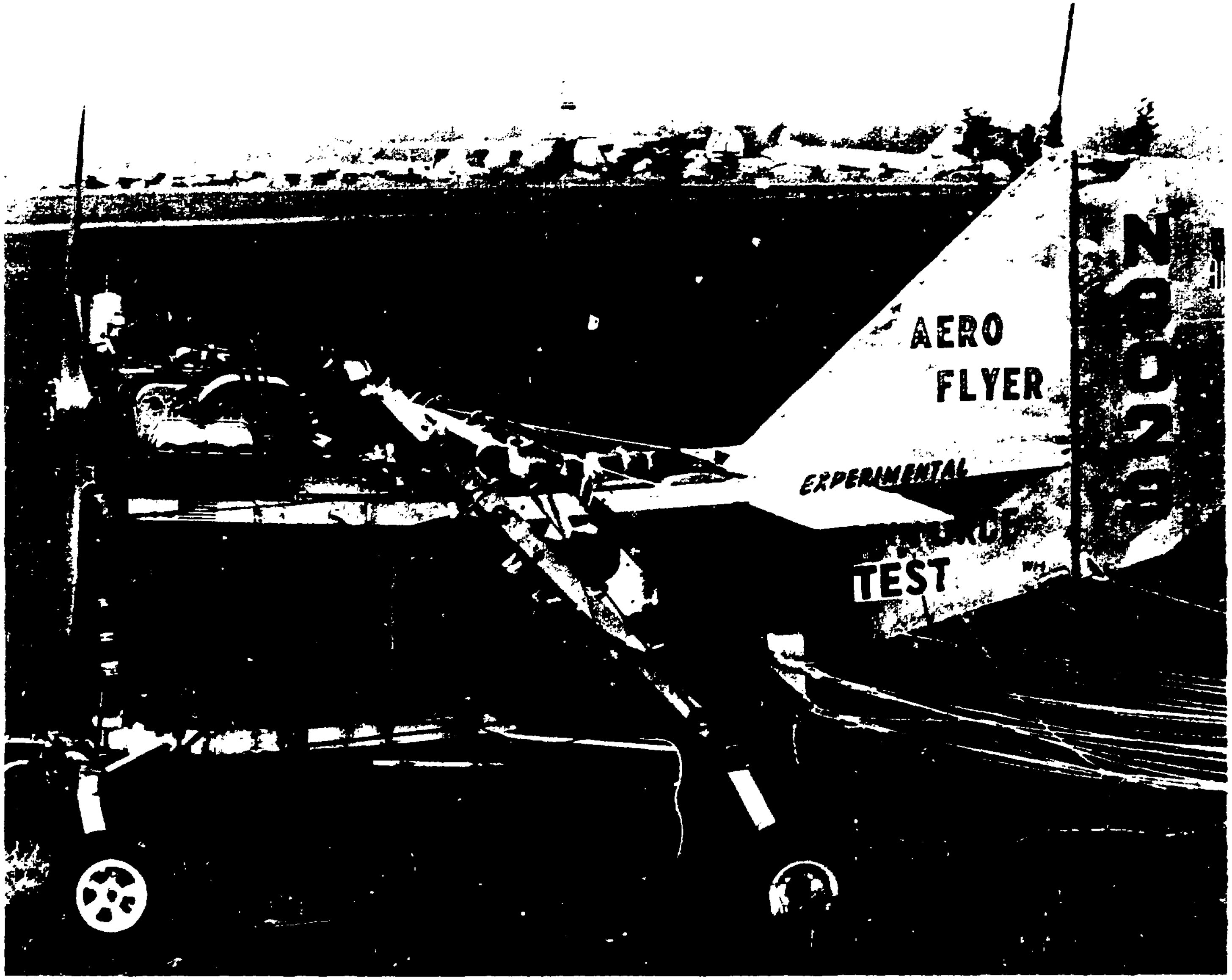


Figure 9 AeroFlyer, F5

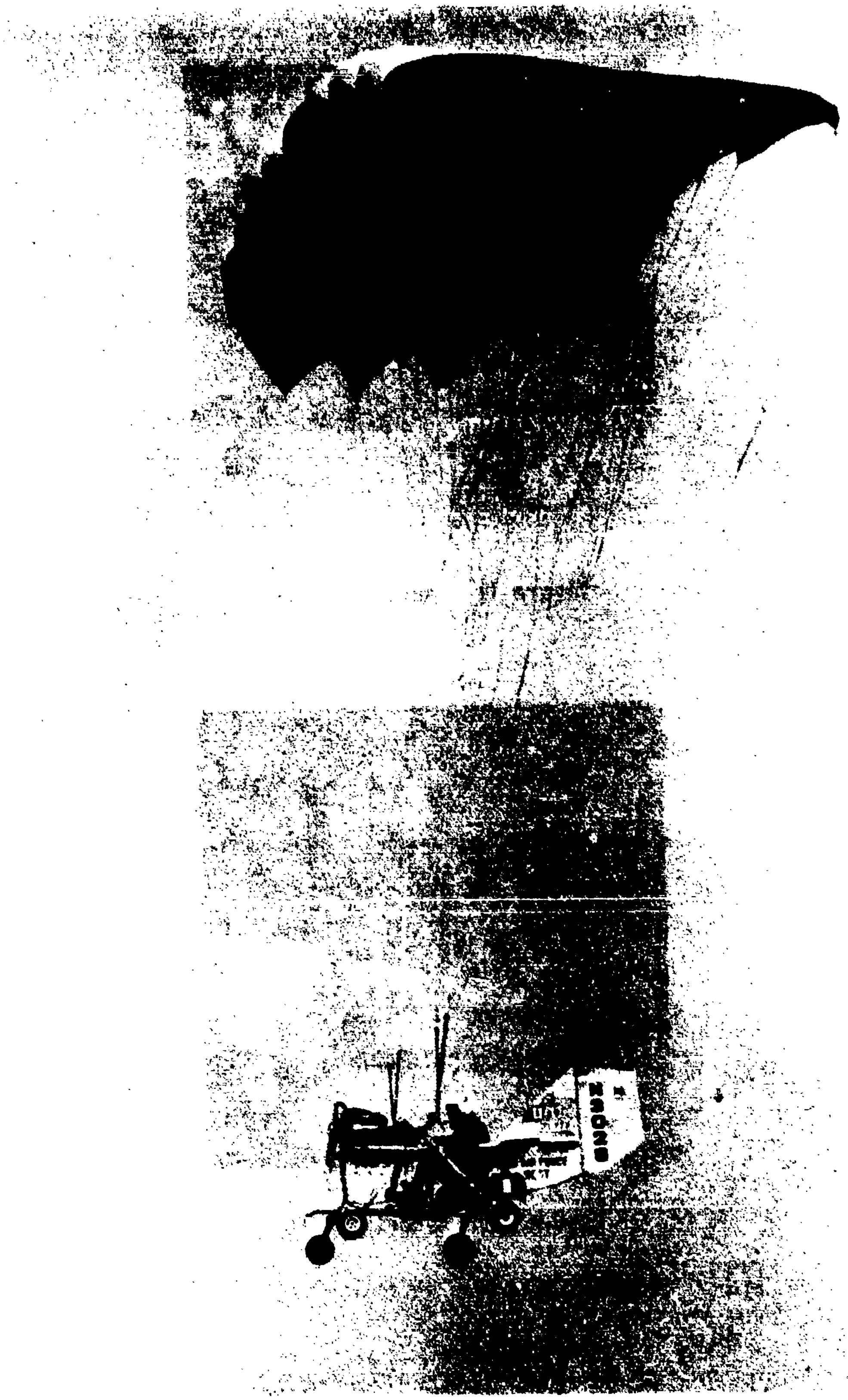


Figure 10 AeroFlyer, F5, in Flight[25]

Figure 11 AeroFlyer, F6

Figure 12 AeroFlyer, F6

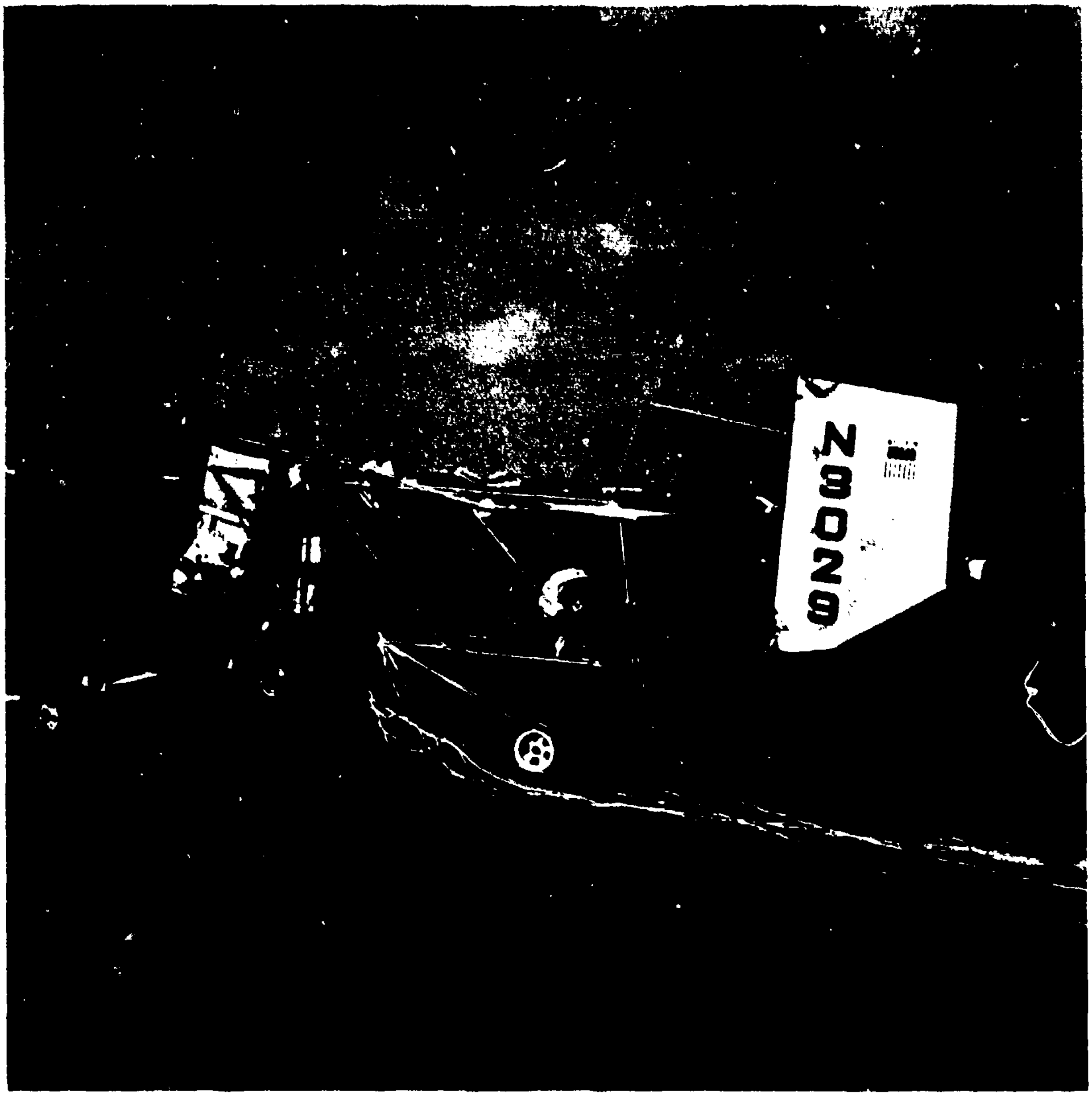


Figure 13   AeroFlyer, F7, Pre Flight #80

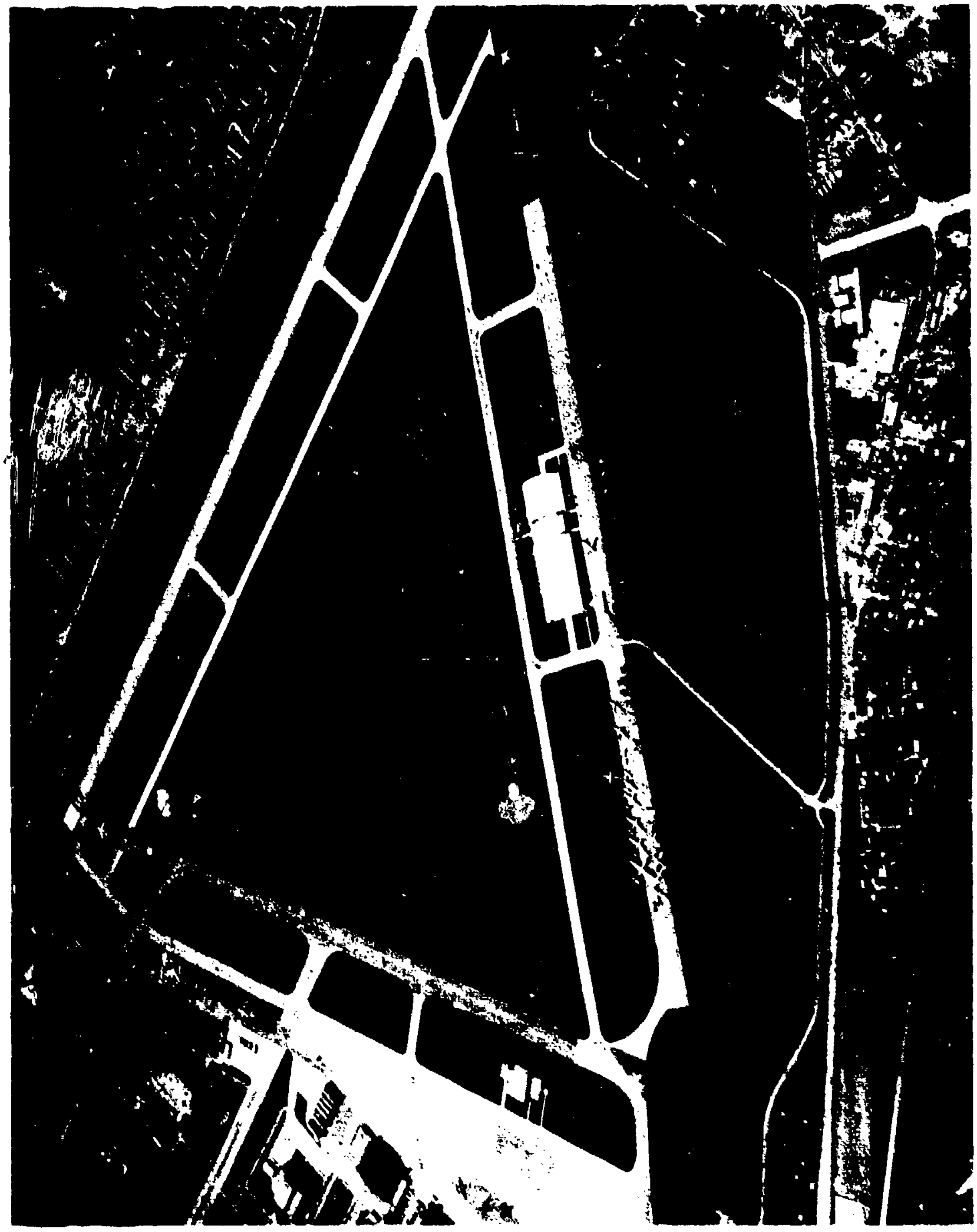


Figure 14 Wright Field

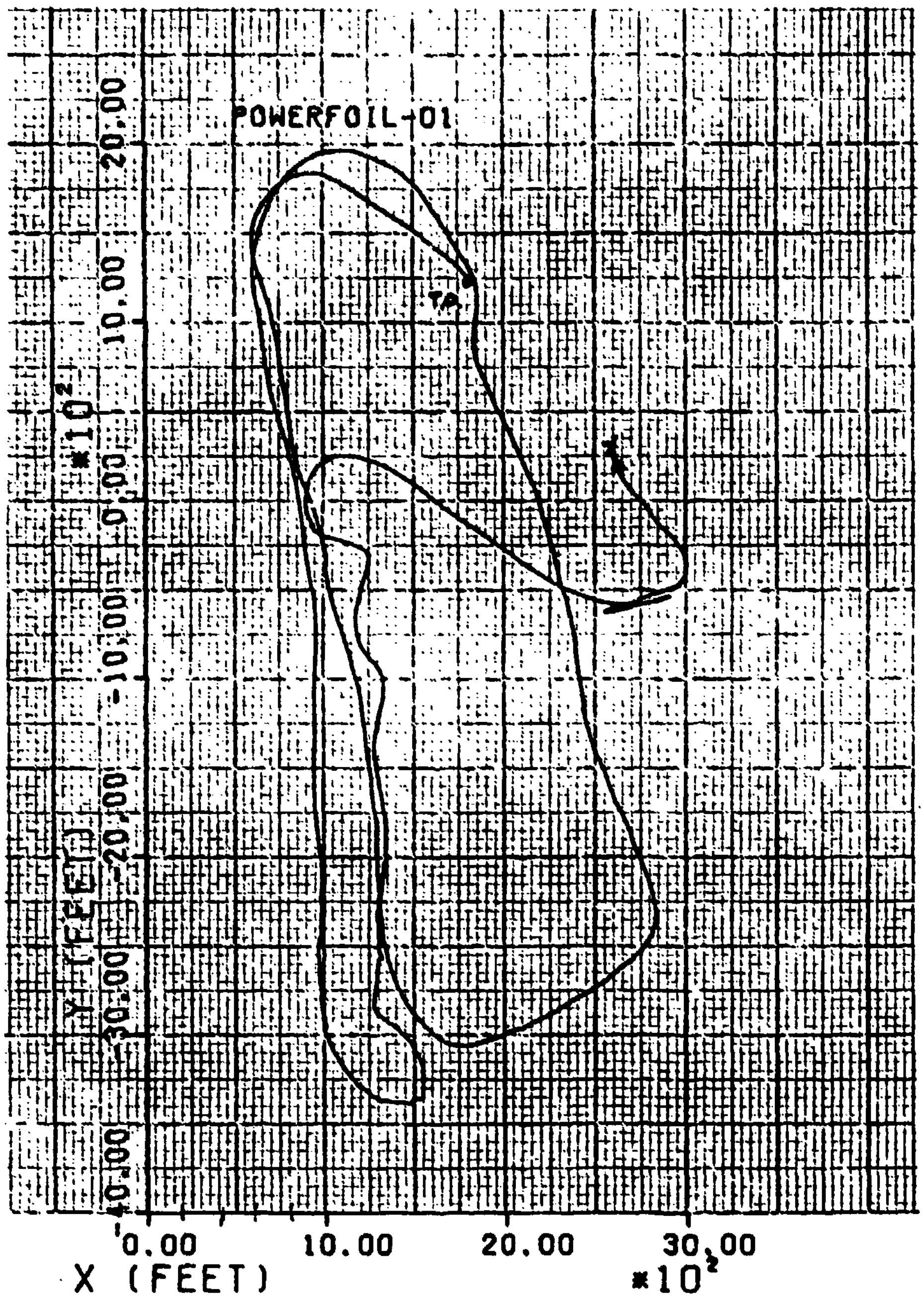


Figure 15 AeroFlyer Wright Field Flight 1 Ground Track

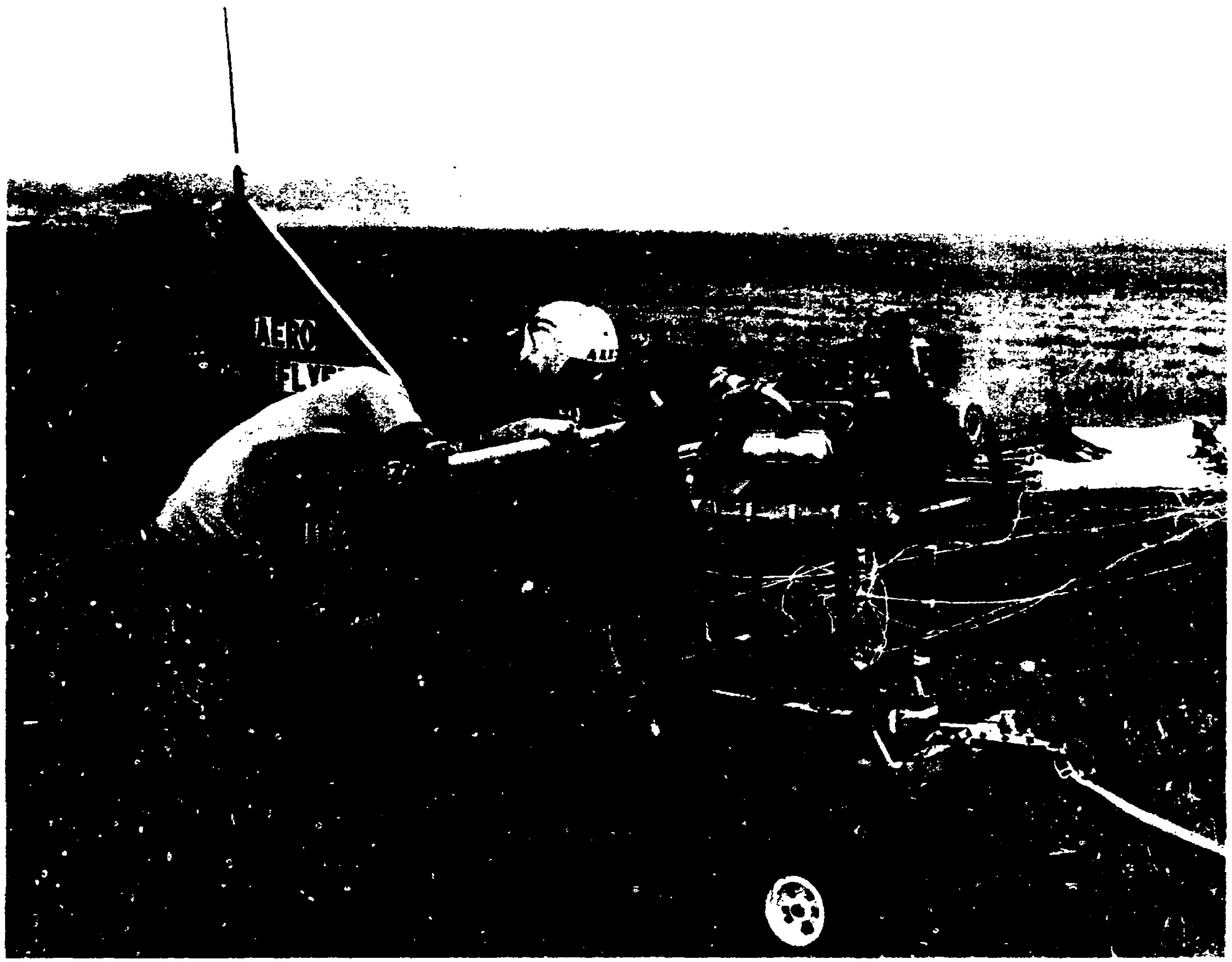


Figure 16 AeroFlyer Engine Check Prior to Flight 1 at Wright Field

Figure 17 AeroFlyer Flight 1, Start of Tow and Parafoil Lift Off

Figure 18 AeroFlyer Flight 1

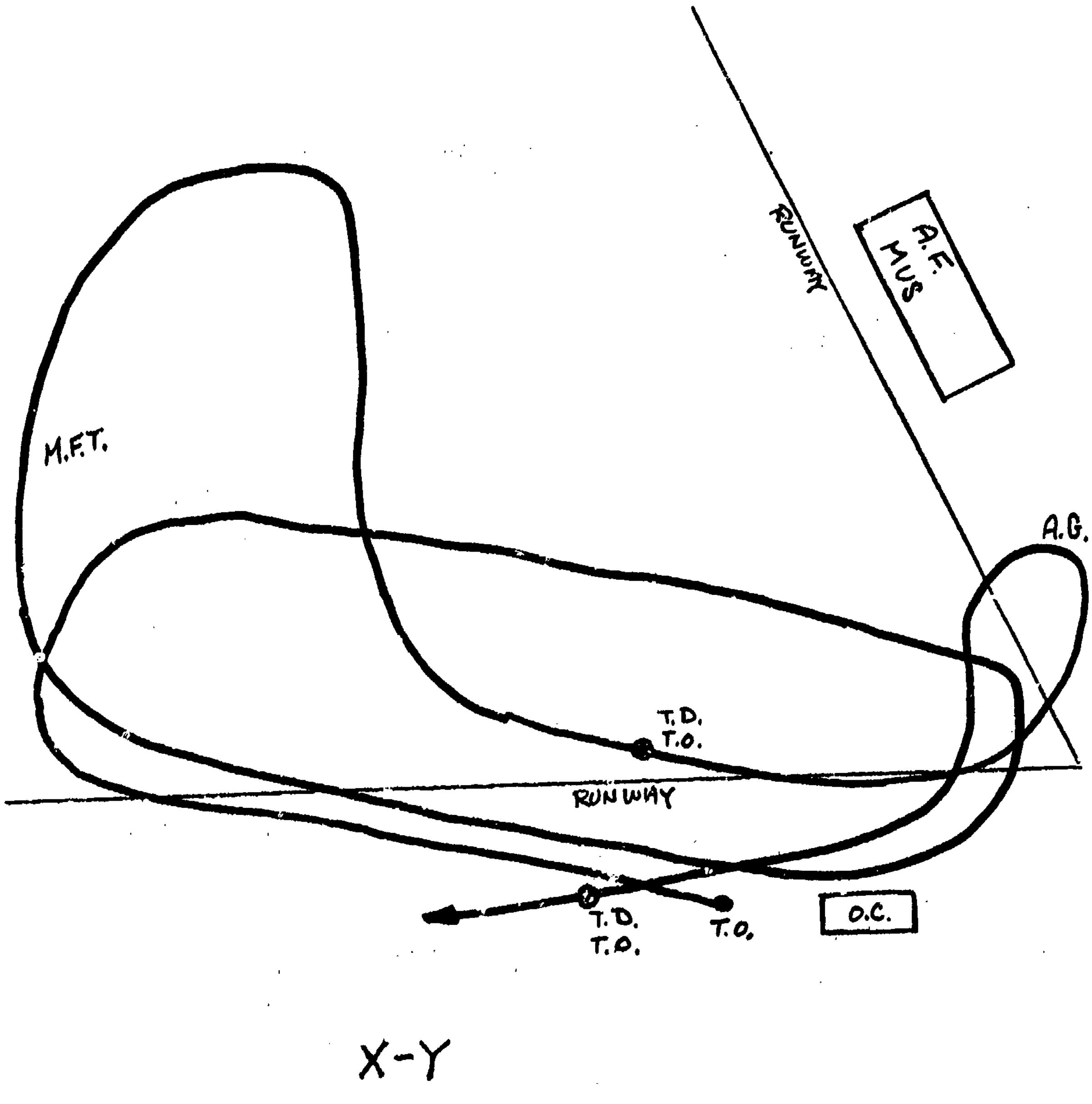


Figure 19 AeroFlyer Wright Field Flight 2 Ground Track
(Demonstration for Press)

Figure 20 AeroFlyer Flight 2. Pre Flight Check Engine Run-up

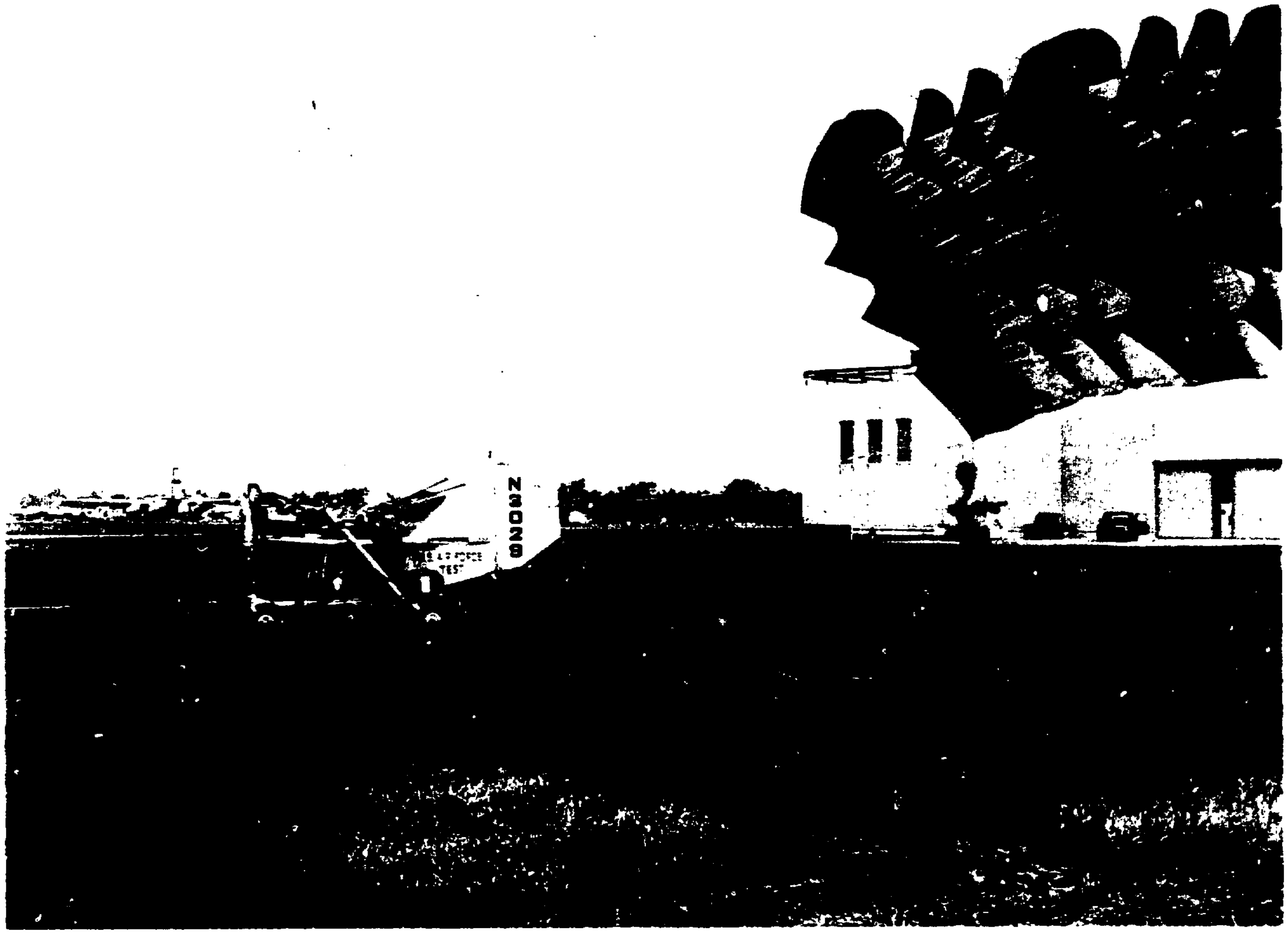


Figure 21 AeroFlyer Flight 2, Initial Tow

Figure 22 AeroFlyer Flight 2, Fly By

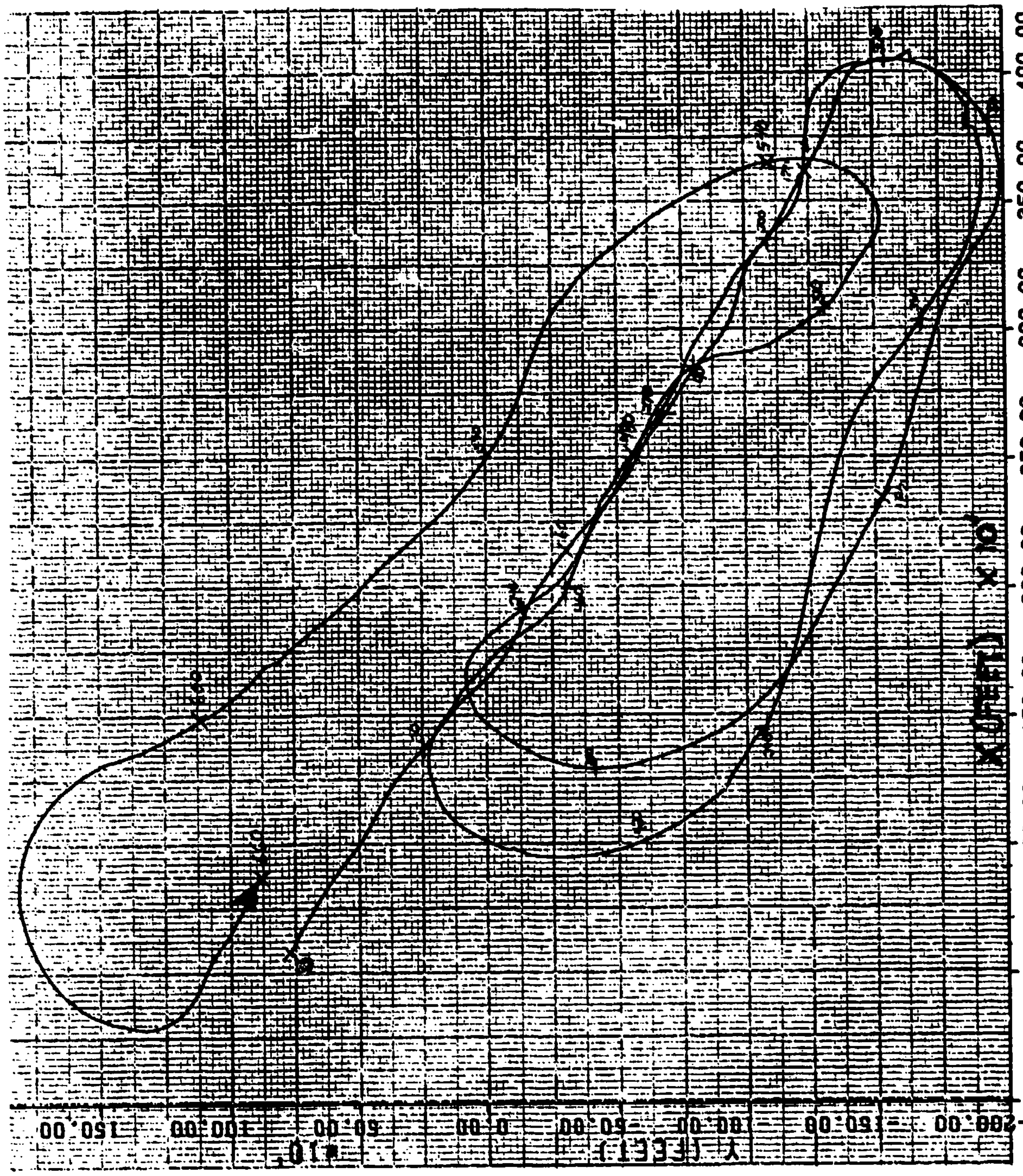


Figure 23 AeroFlyer Wright Field Flight 3 Ground Track

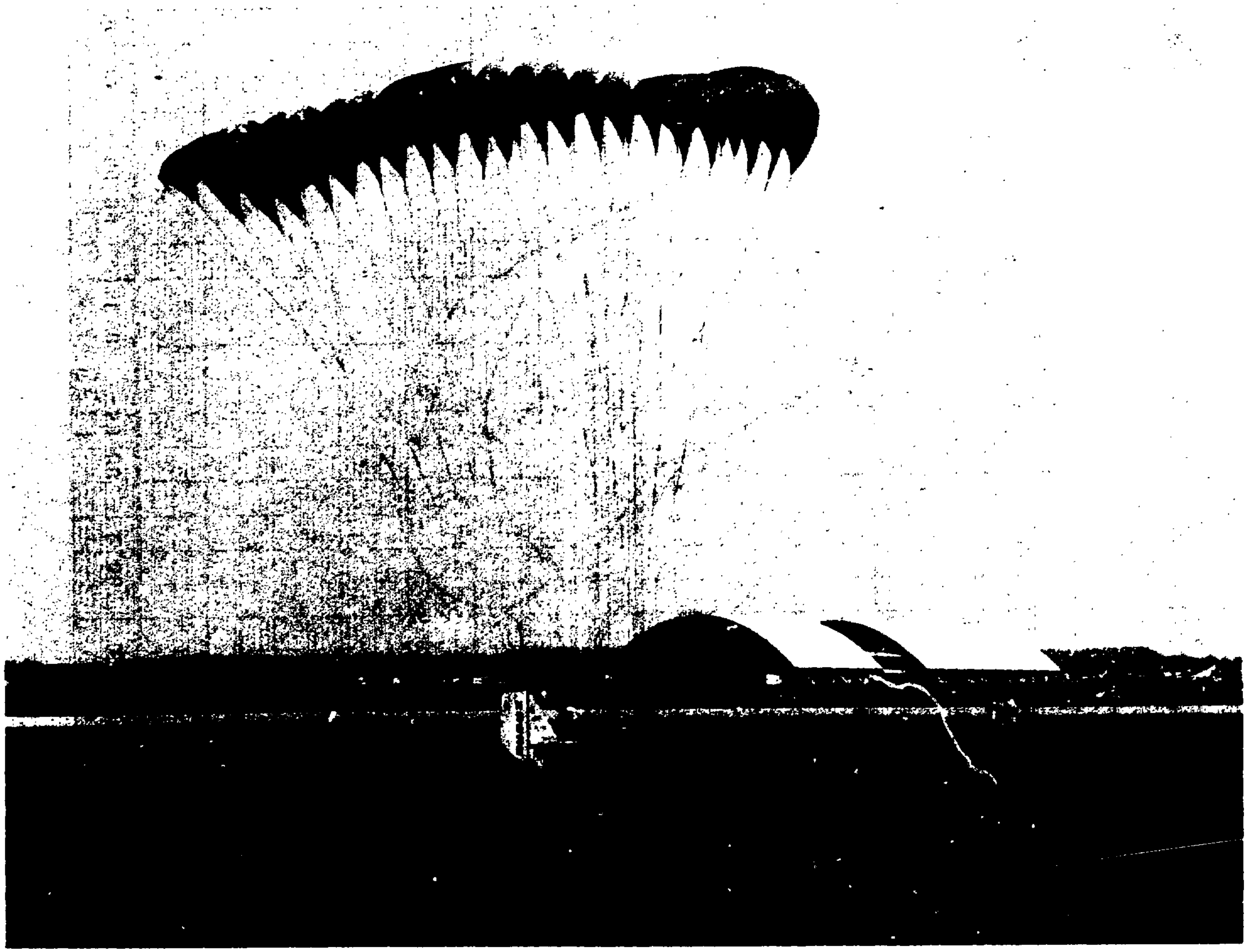


Figure 24   AeroFlyer Flight 3 Take-Off Two

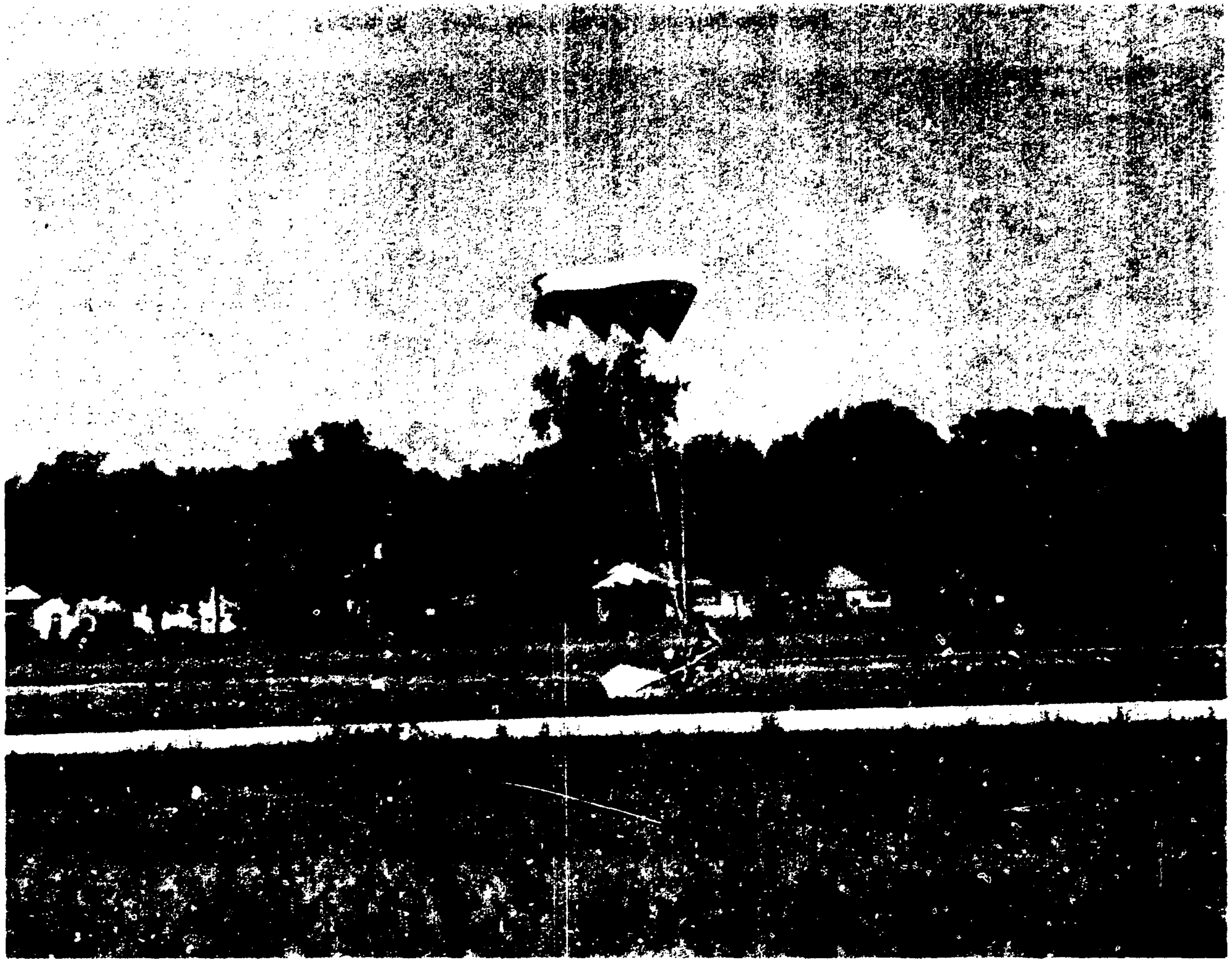


Figure 25   AeroFlyer Flight 3, Landing

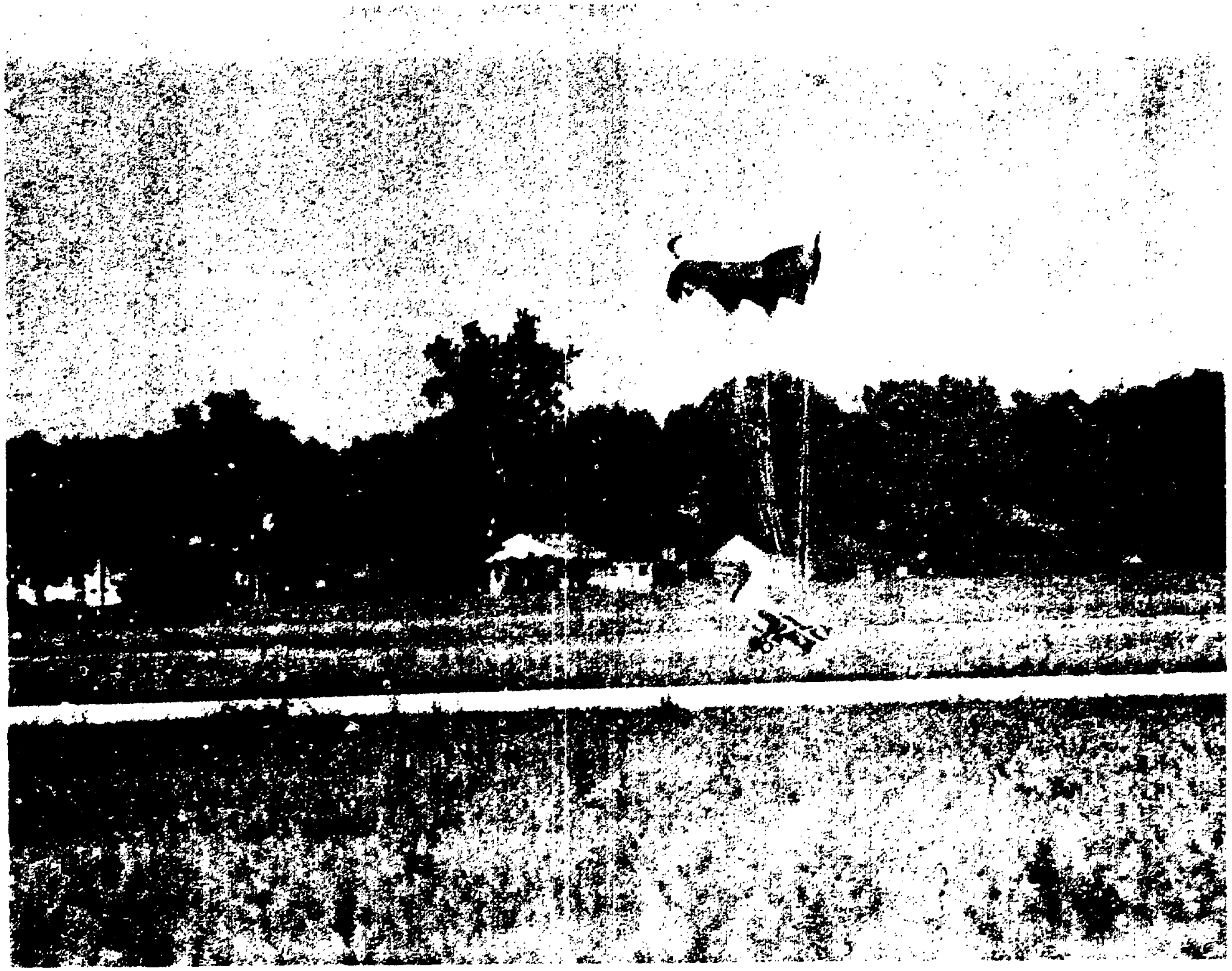


Figure 26 AeroFlyer Flight 3, Landing Nose Over

Figure 27 AeroFlyer Flight 3, Landing Nose Over

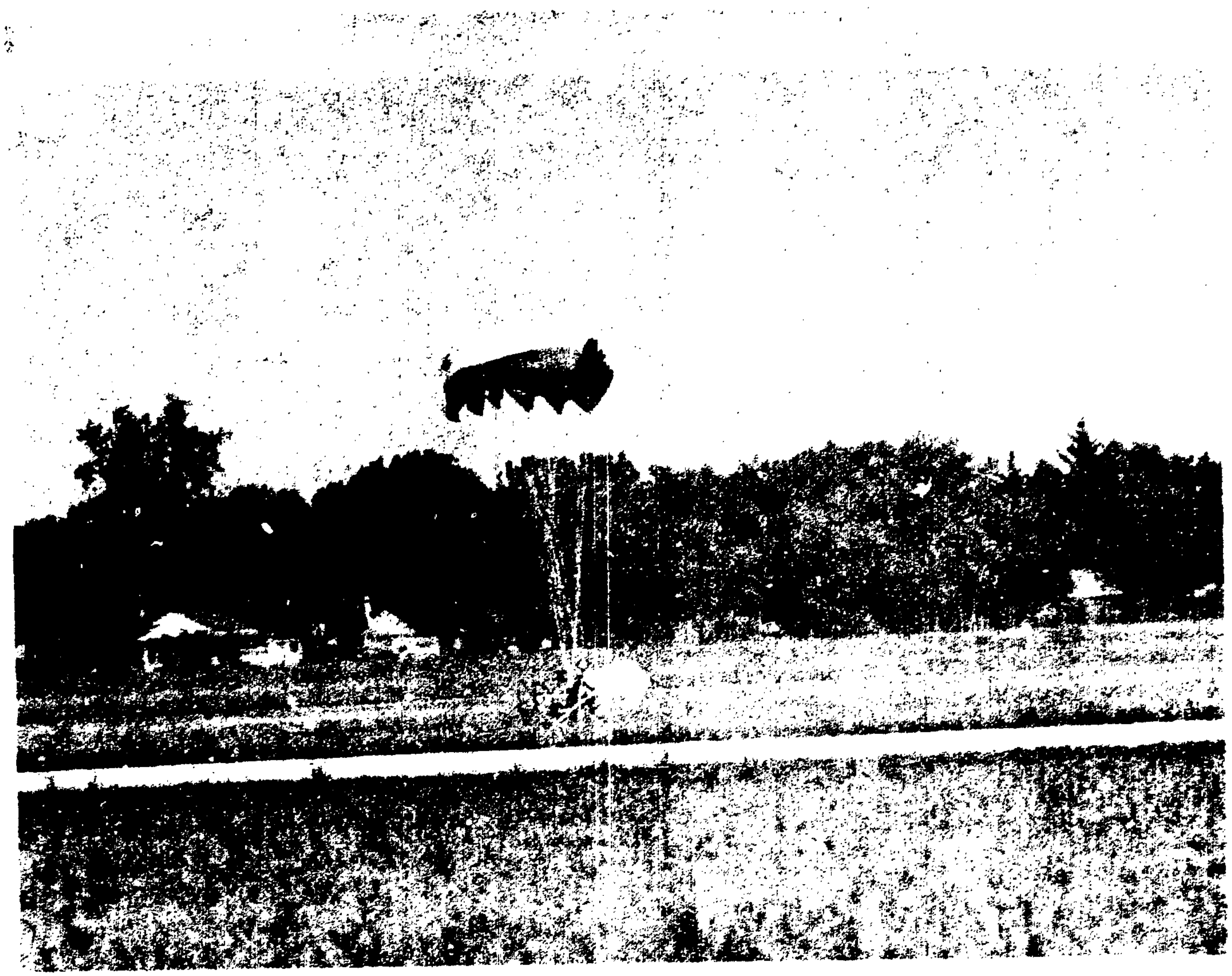


Figure 28 AeroFlyer Flight 3, Landing Nose Over

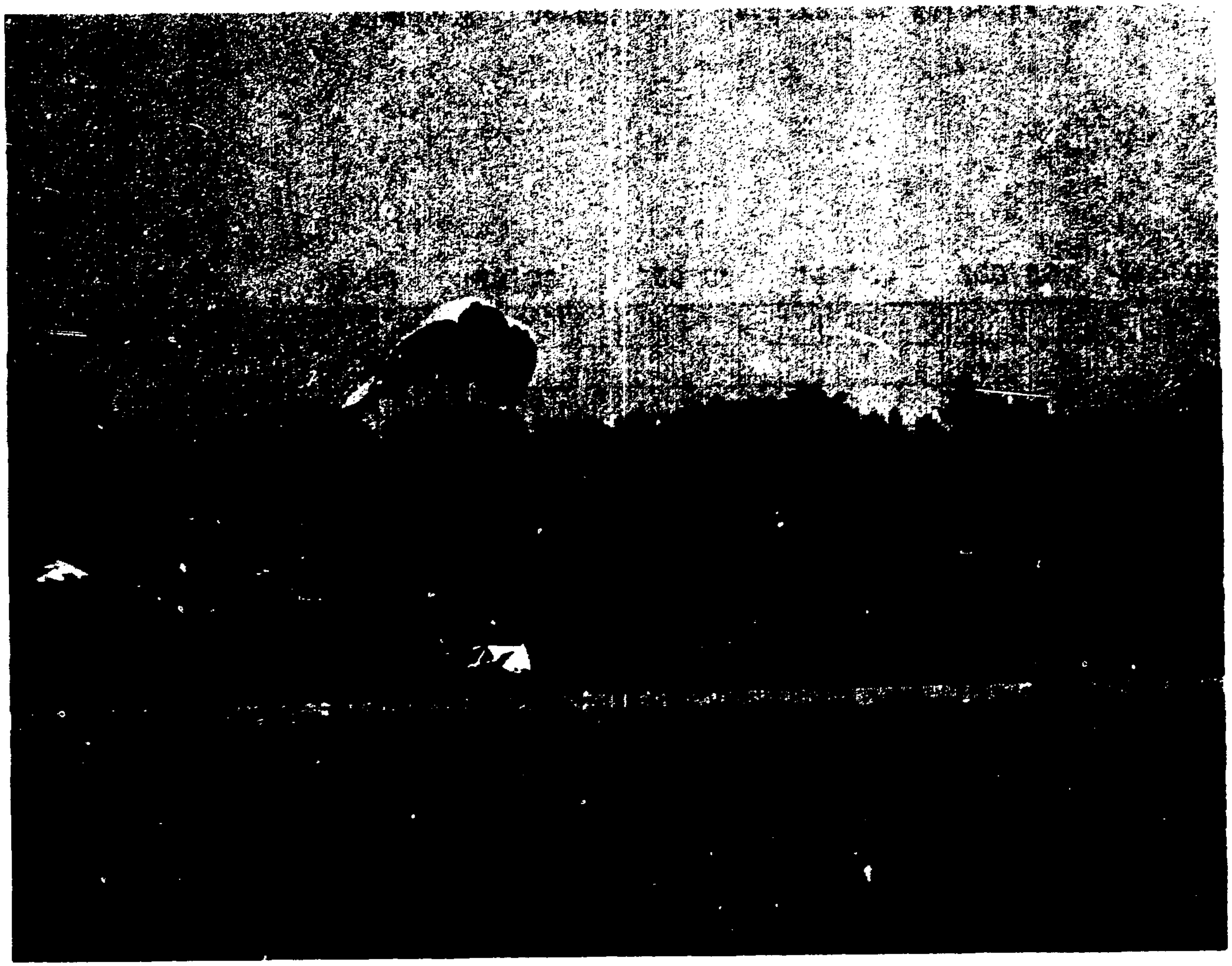


Figure 29 AeroFlyer Flight 3, Landing Nose Over

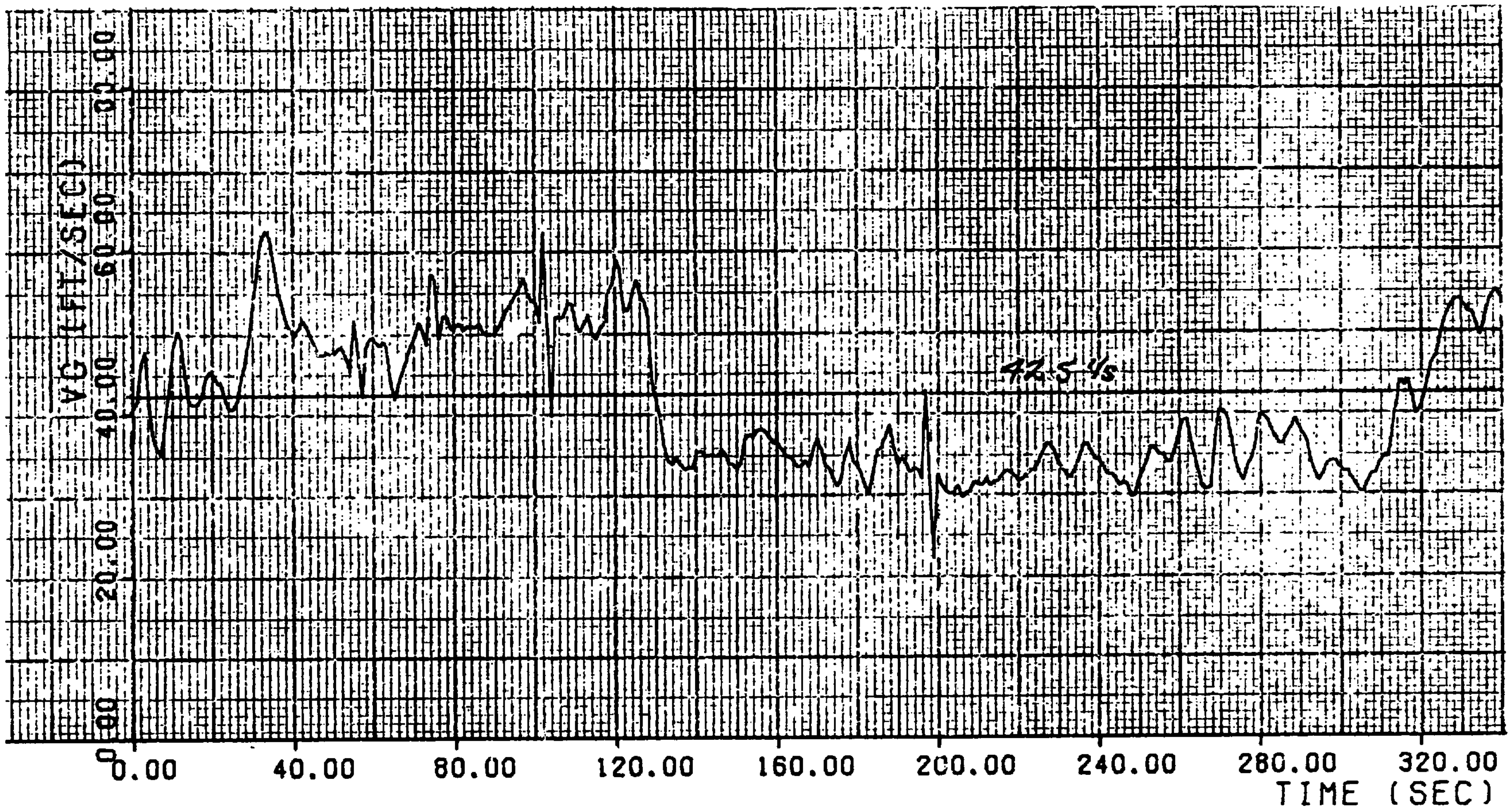


Figure 30 AeroFlyer 1 Uncorrected Velocity

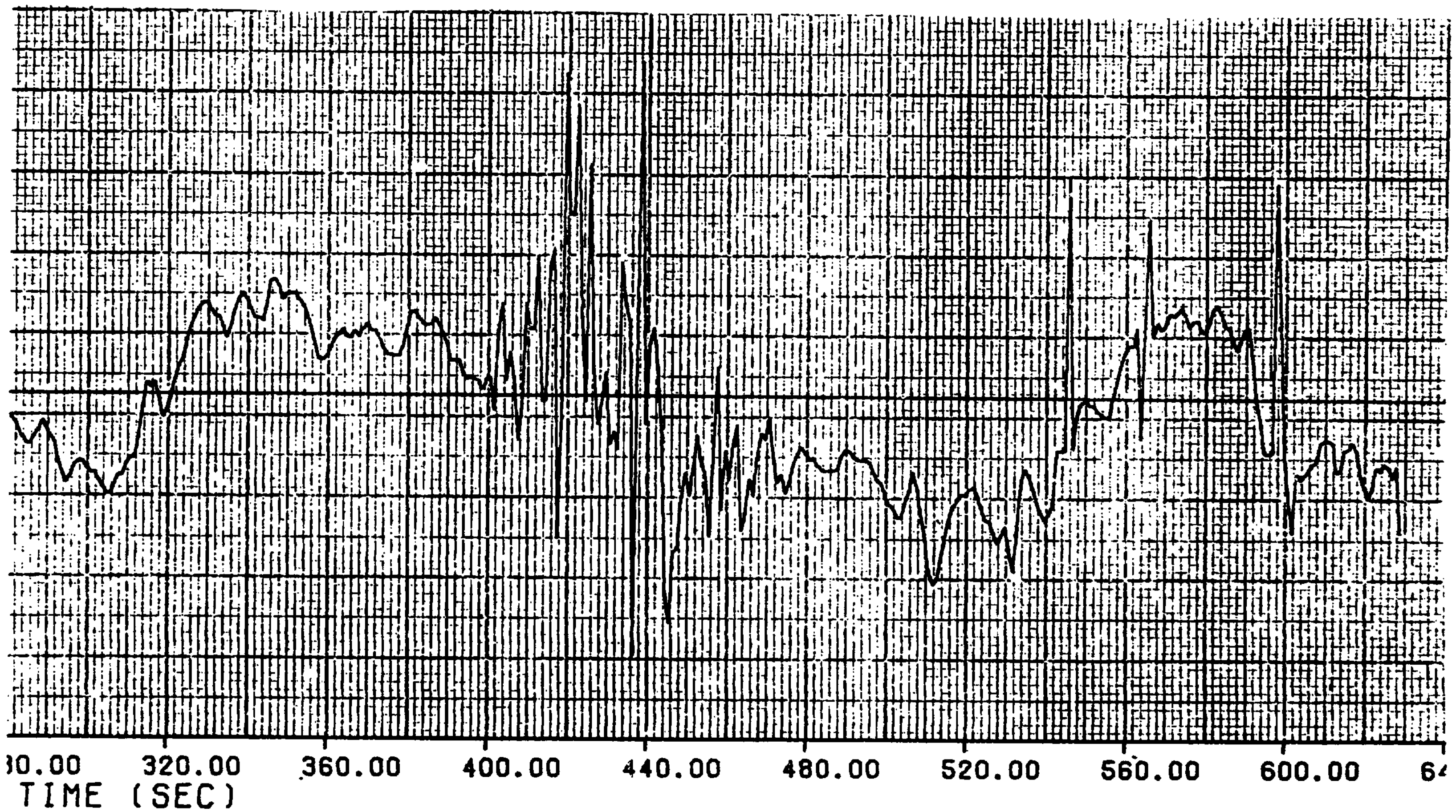


Figure 30 (Continued)

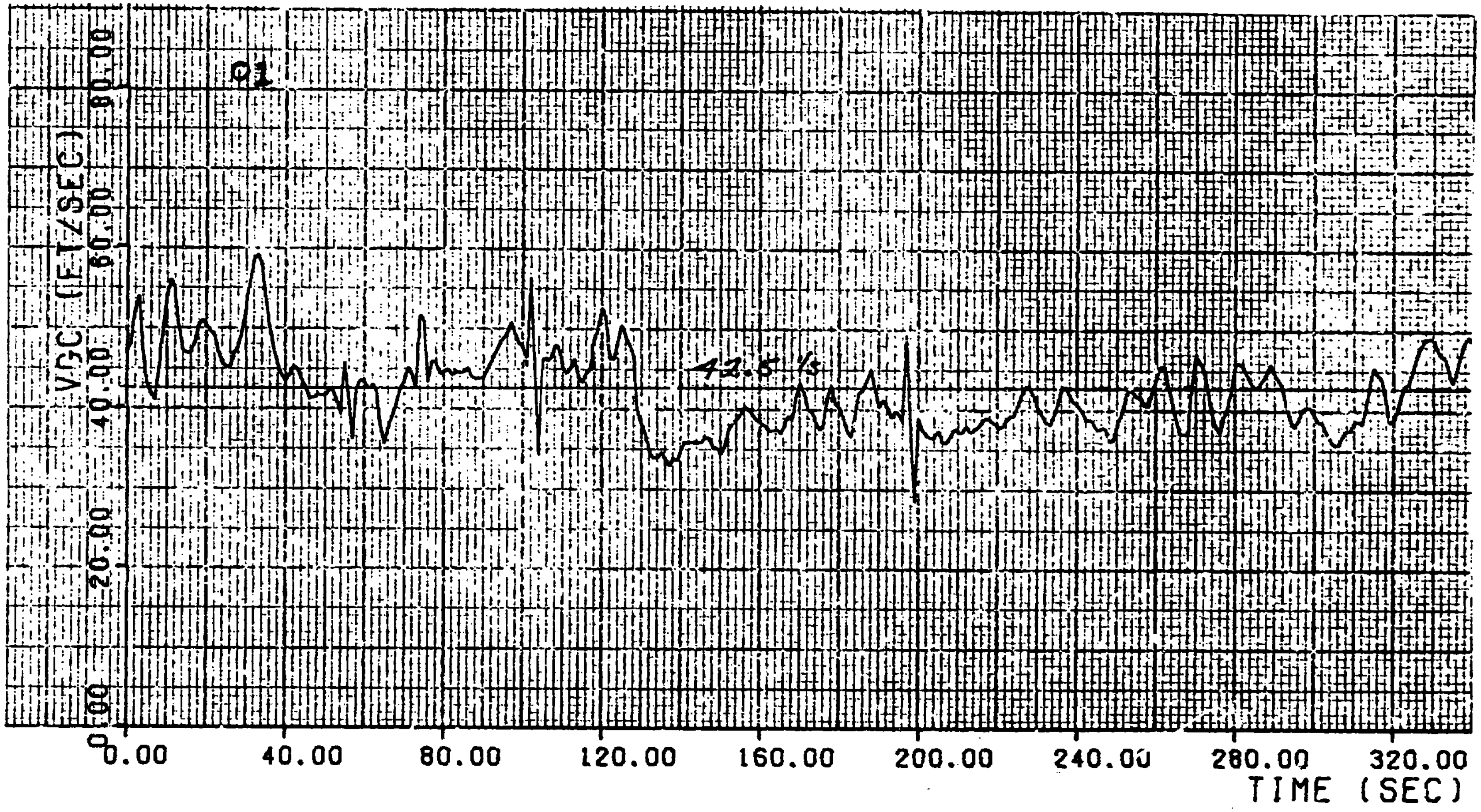


Figure 31 AeroFlyer Flight 1 Wind Corrected Velocity

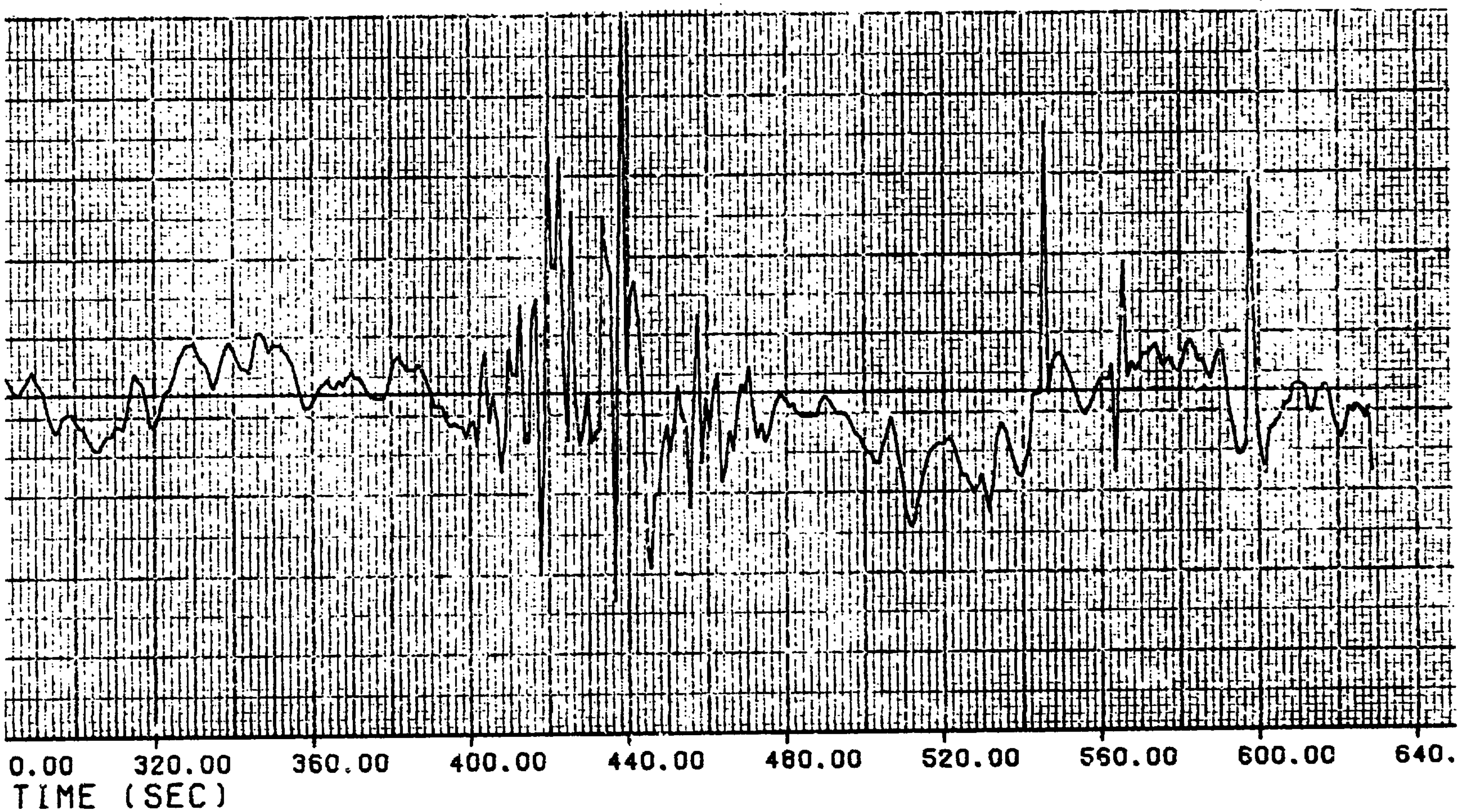


Figure 31 (Continued)

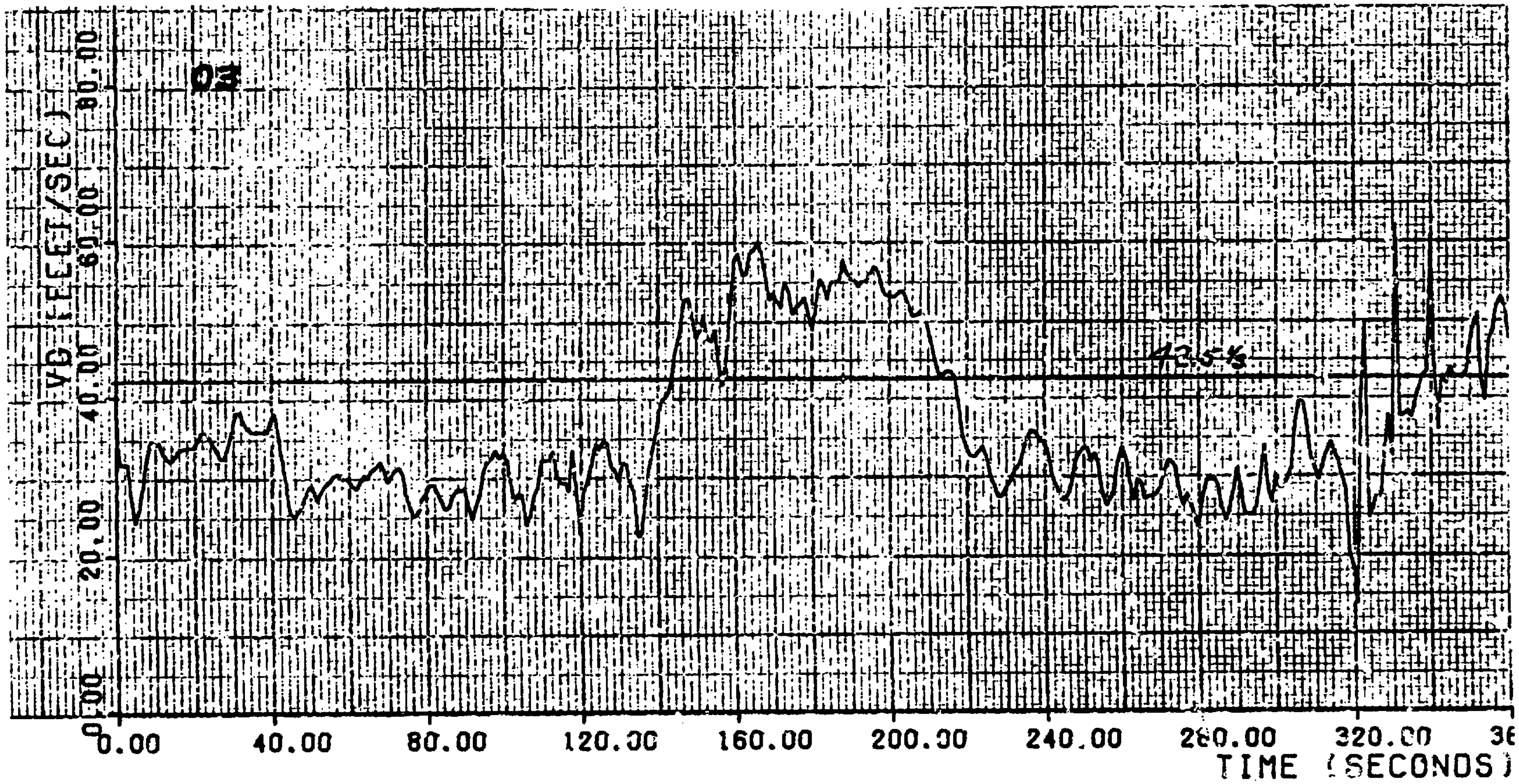


Figure 32 AeroFlyer Flight 3 Uncorrected Velocity

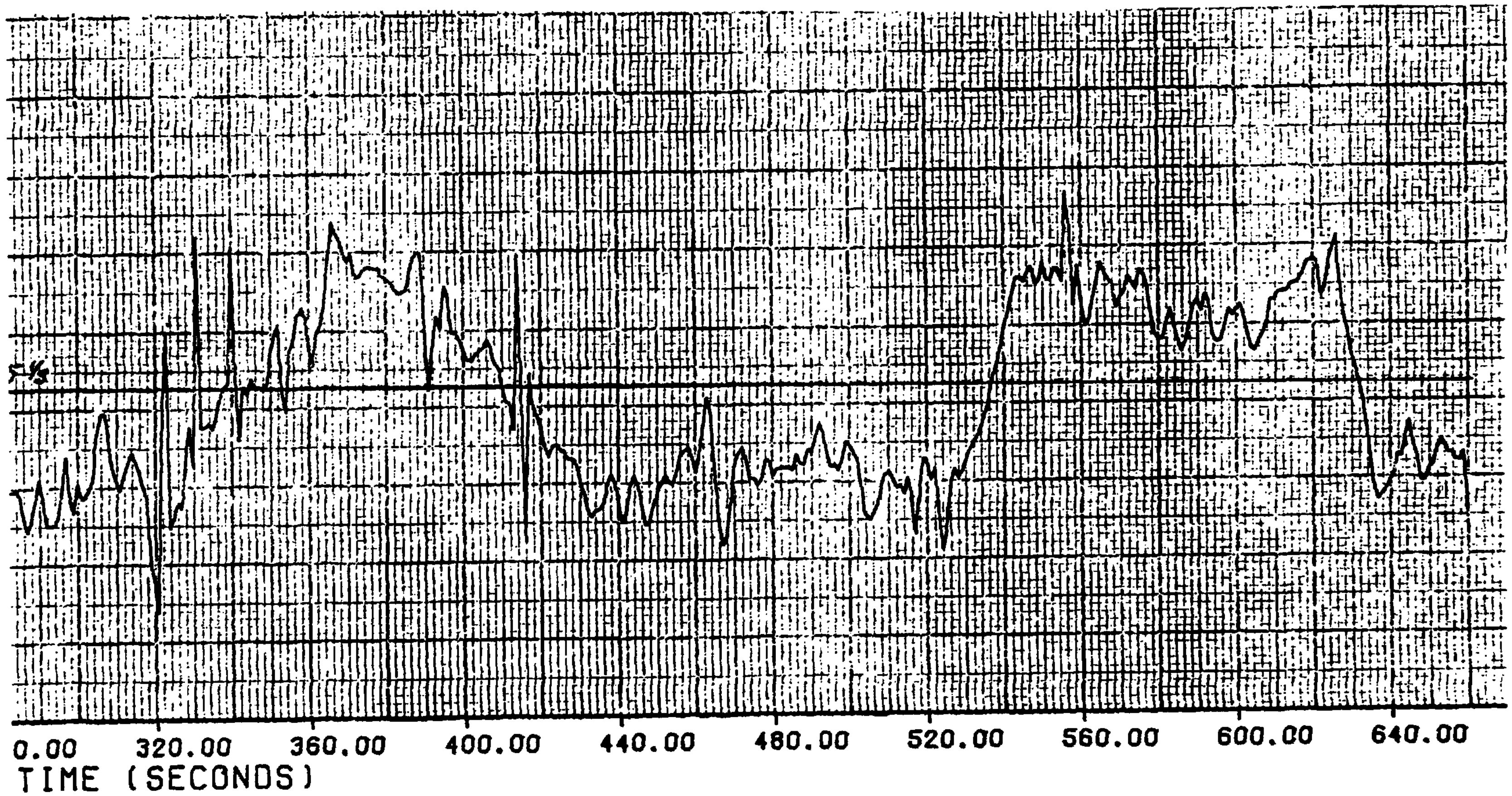


Figure 32 (Continued)

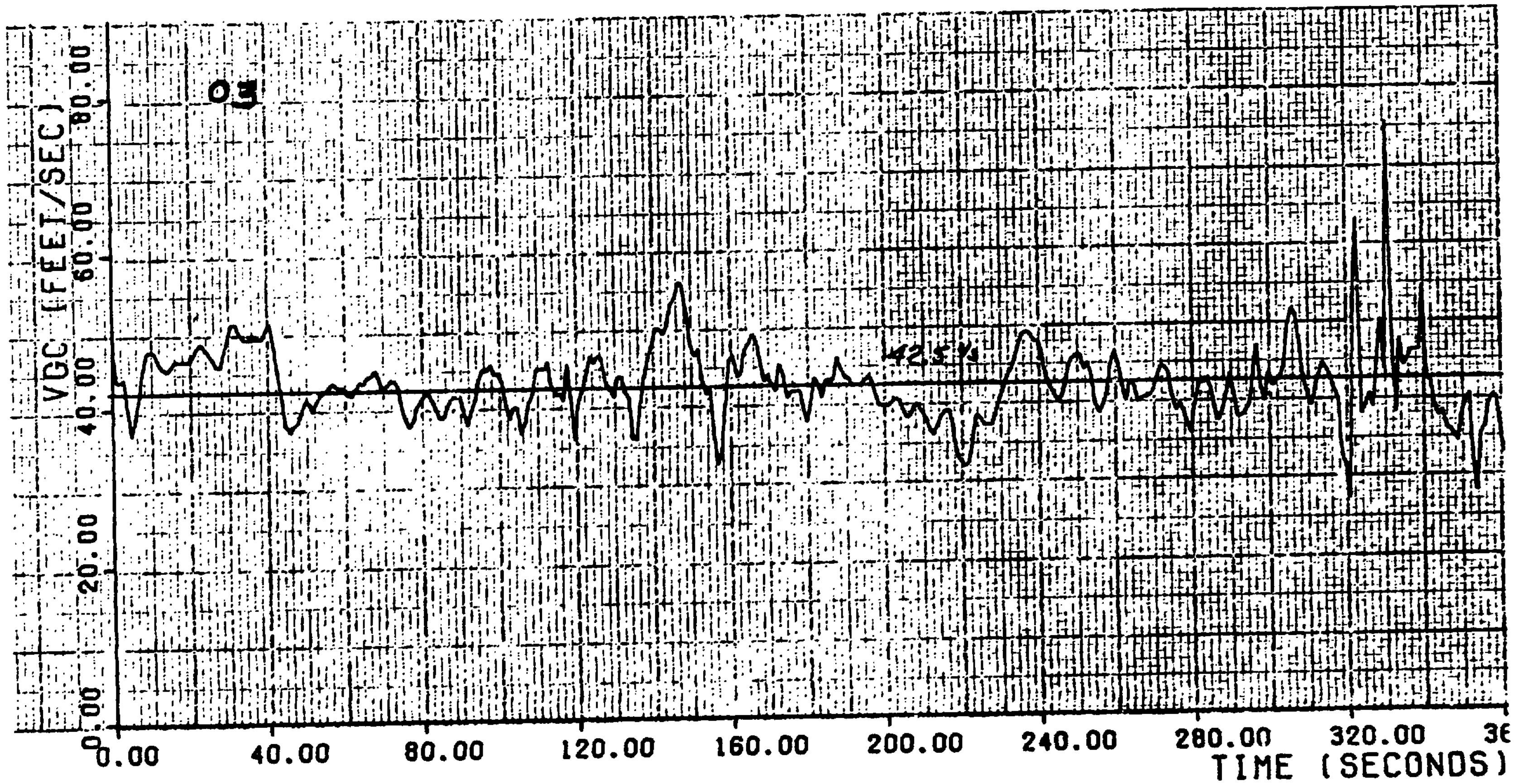


Figure 33 AeroFlyer Flight 3 Wind Corrected Velocity

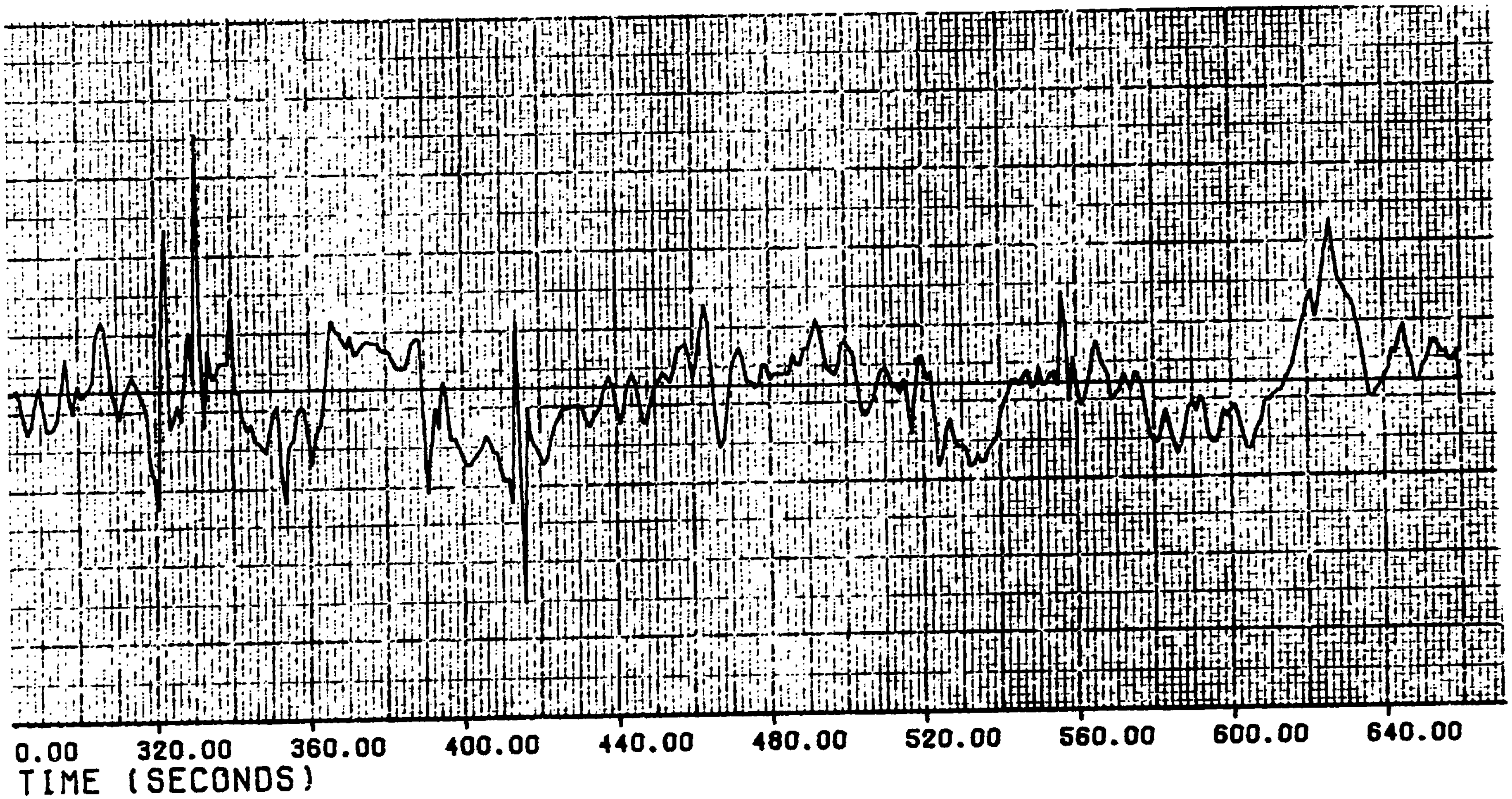


Figure 33 (Continued)

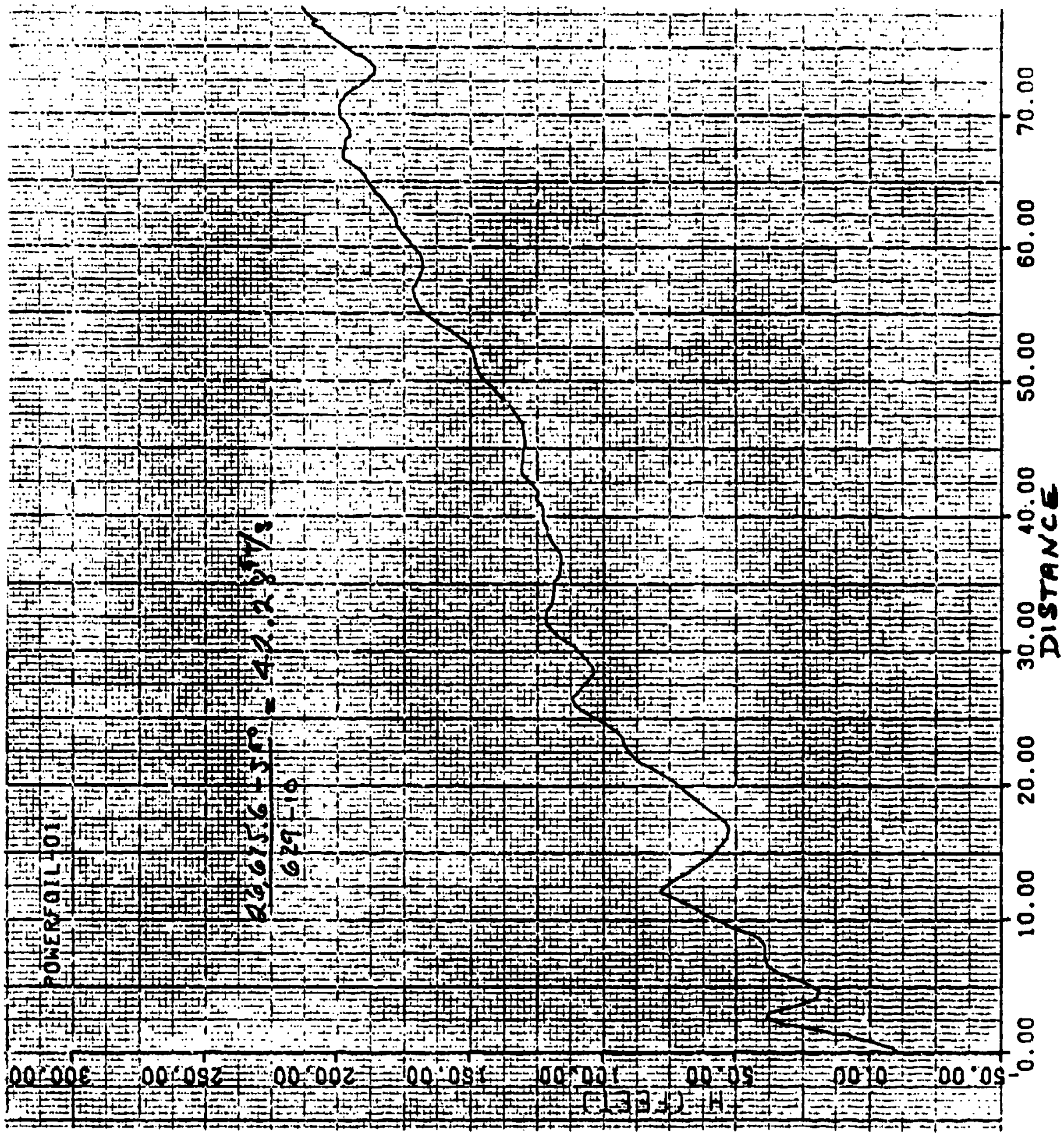
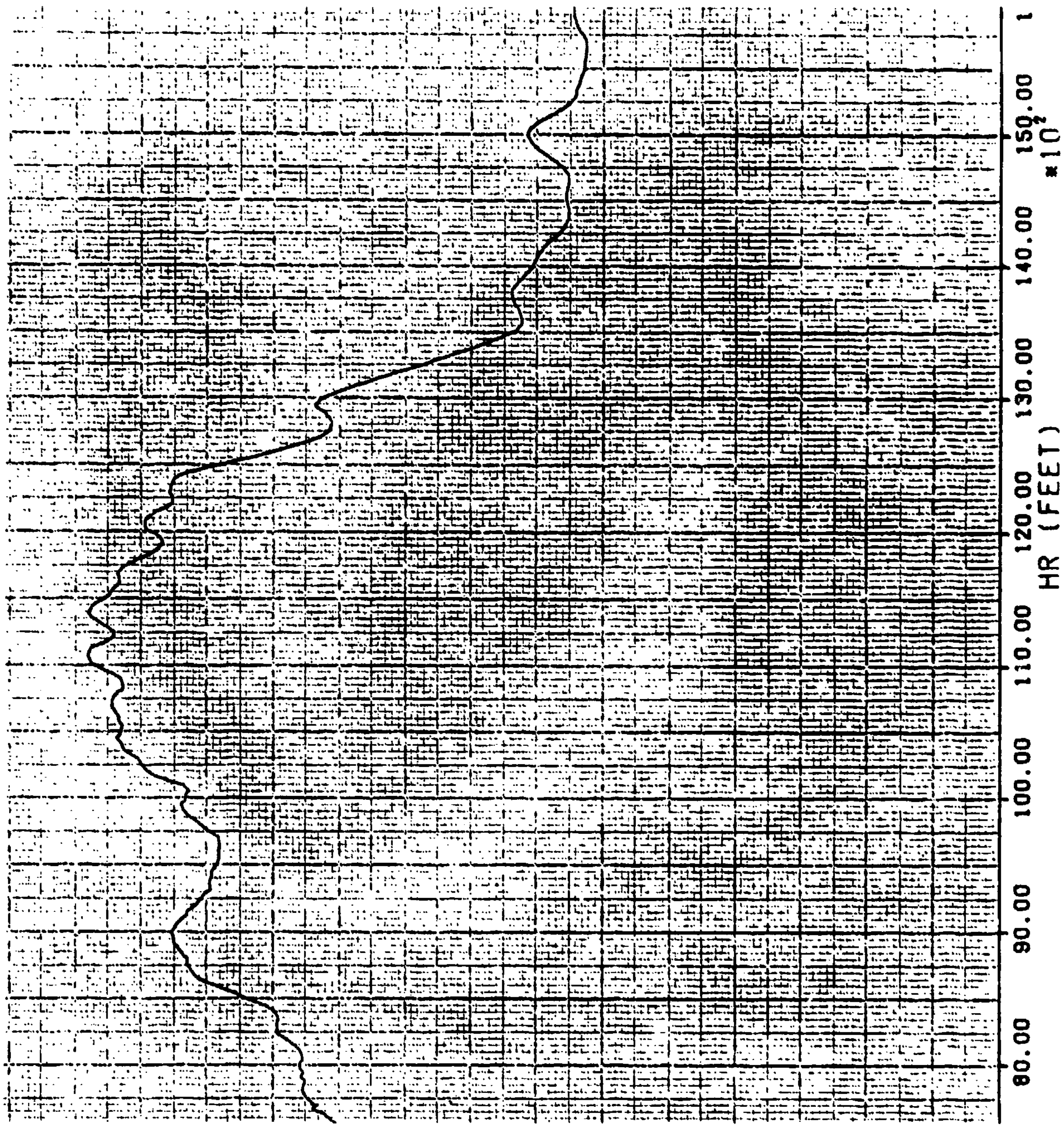


Figure 34 AeroFlyer Flight 1 Altitude vs Distance



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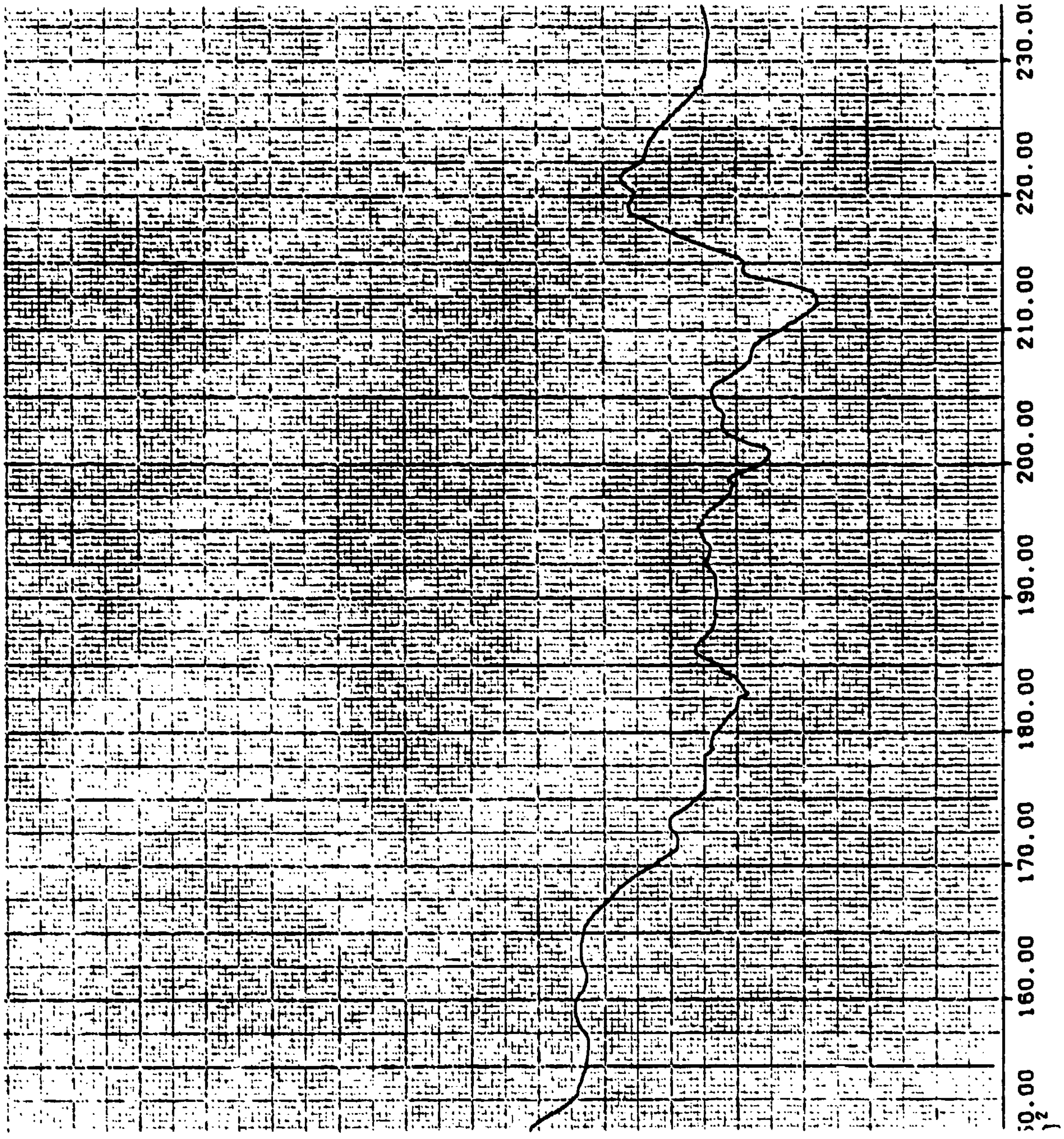

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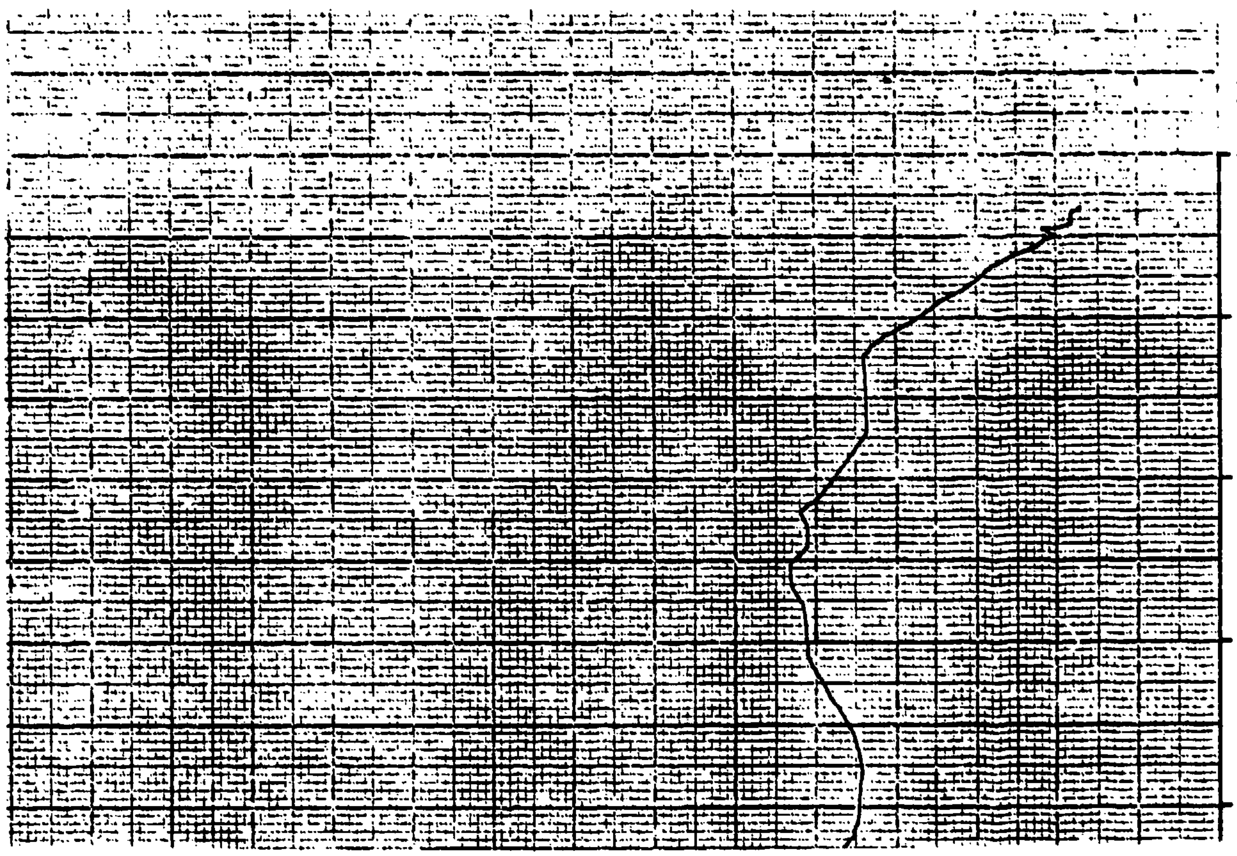


Figure 34 (Continued)

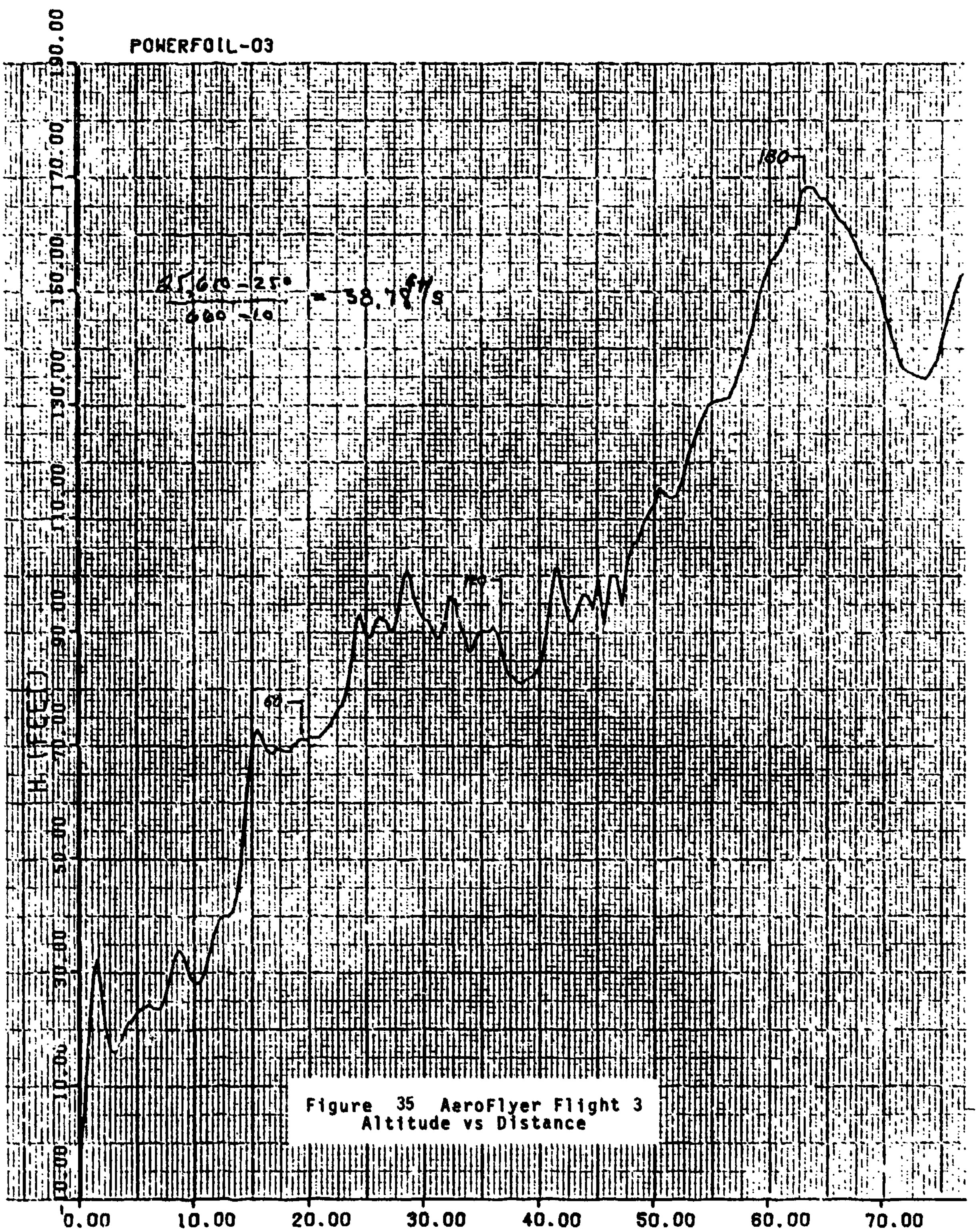


Figure 35 AeroFlyer Flight 3
Altitude vs Distance

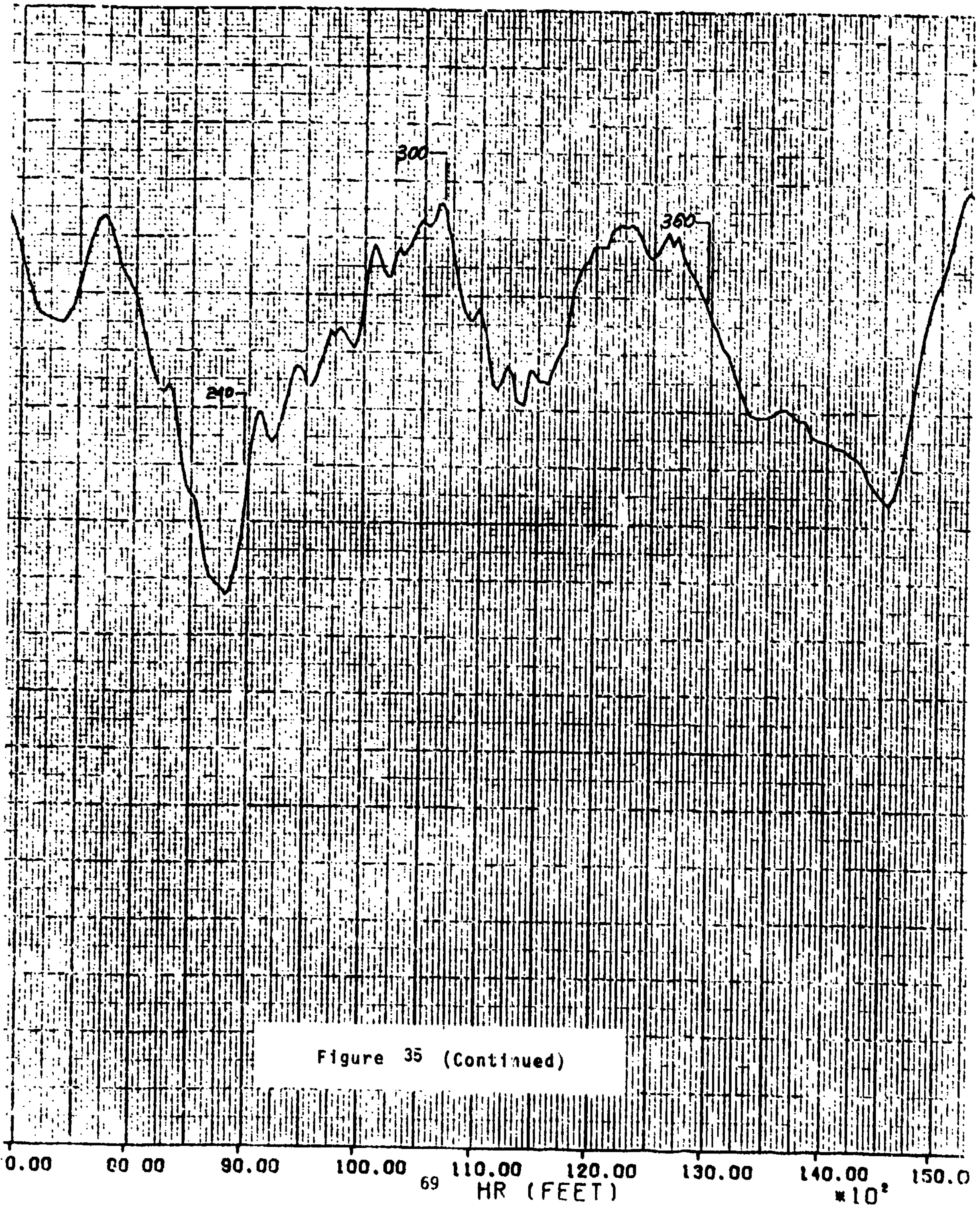
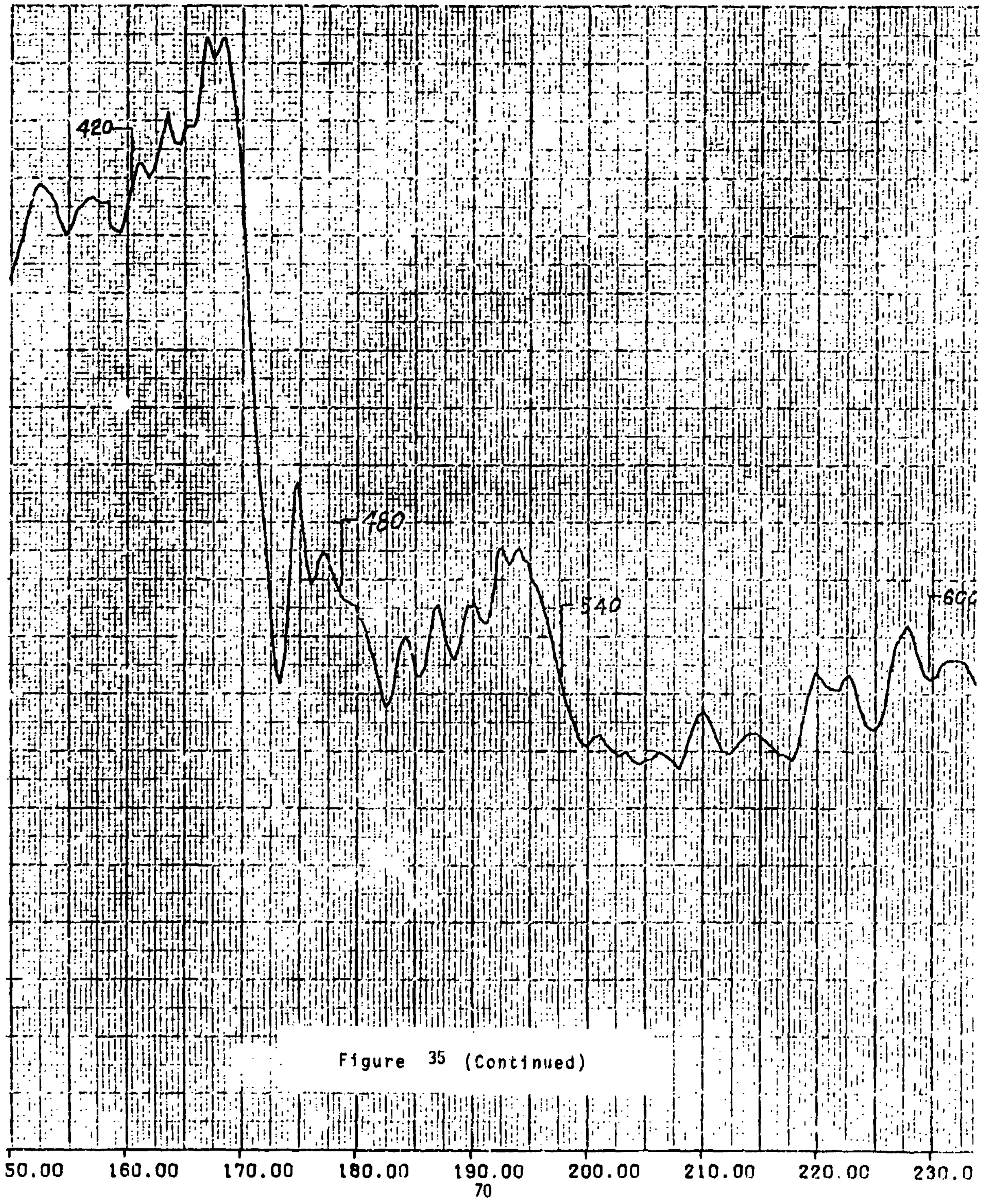


Figure 35 (Continued)



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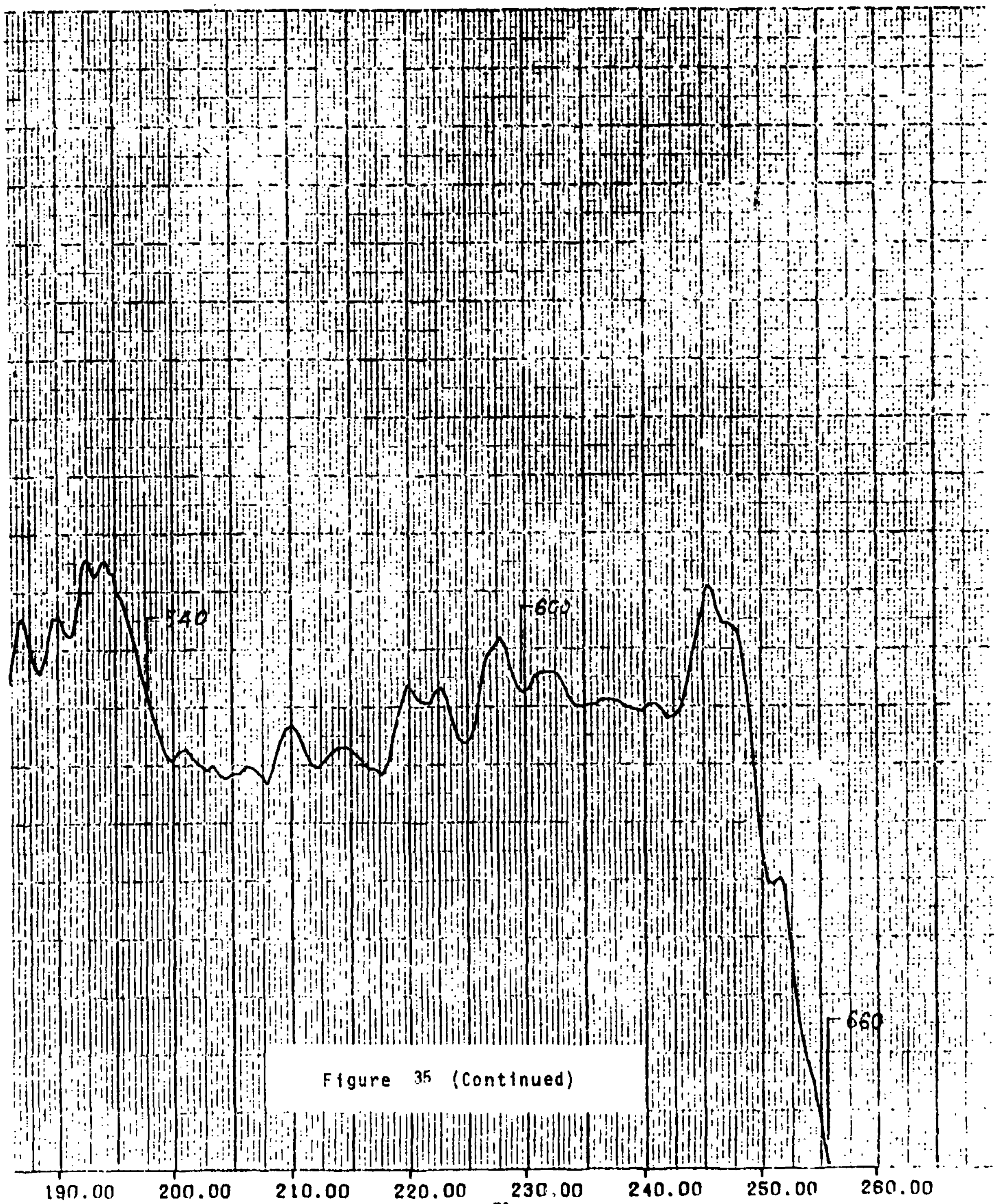

Figure 35 (Continued)

	Flight 1	Flight 2	Flight 3
1	C225LR*	C90RR	C90RR
2	C90LR	C90RR	C90RR
3	C90LR	L90RRW	L90RR
4	L45RR**	D45RRW	L90RR
5	L45LR	D45RRW	L90RR
6	L180LR	L180RMF****	L90RR
7	L90LR	L90RRW	L45RR
8	L90LRW***	D90LRW	L45LR
9	L45LR	C90LRW	L90RR
10	L45RRW	L180LRW	L90RR
11	Gust Left	D90RRW	C45RR
12	L180RRW	D90RRW	C45RR
13	D45LR		L180LR
14	D90LRW		L45LR
15			L45RR
16			L45RR
17			D135RR
18			D90LRW

*Climb 225^{o} Left Rudder Turn

**Level 45^{o} Right Rudder Turn

***Level 90^{o} Left Rudder and Wing Deflection Turn

****Level 180 Right Magic Flare Turn

Figure 36 Summary of Turns

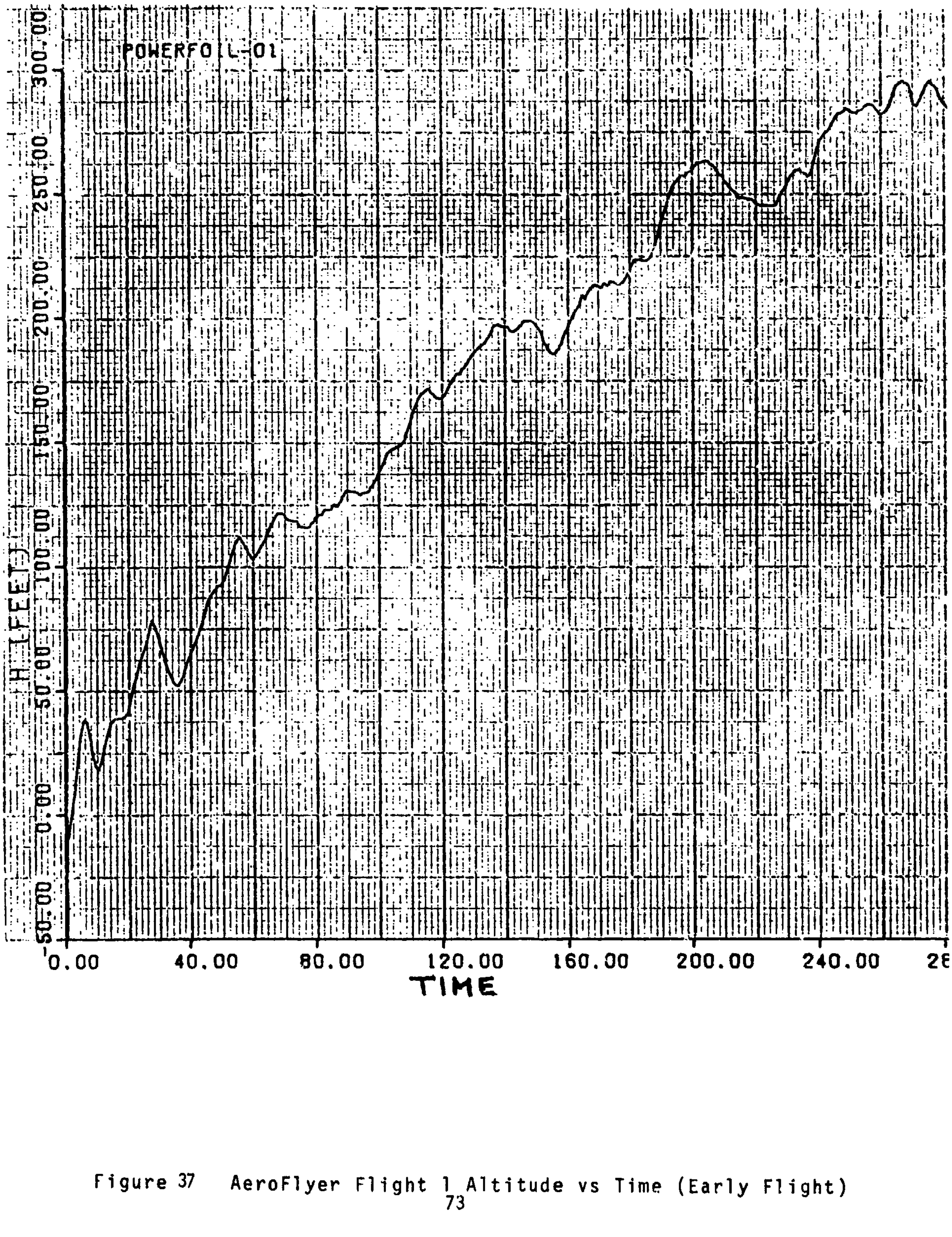

Figure 37 AeroFlyer Flight 1 Altitude vs Time (Early Flight)

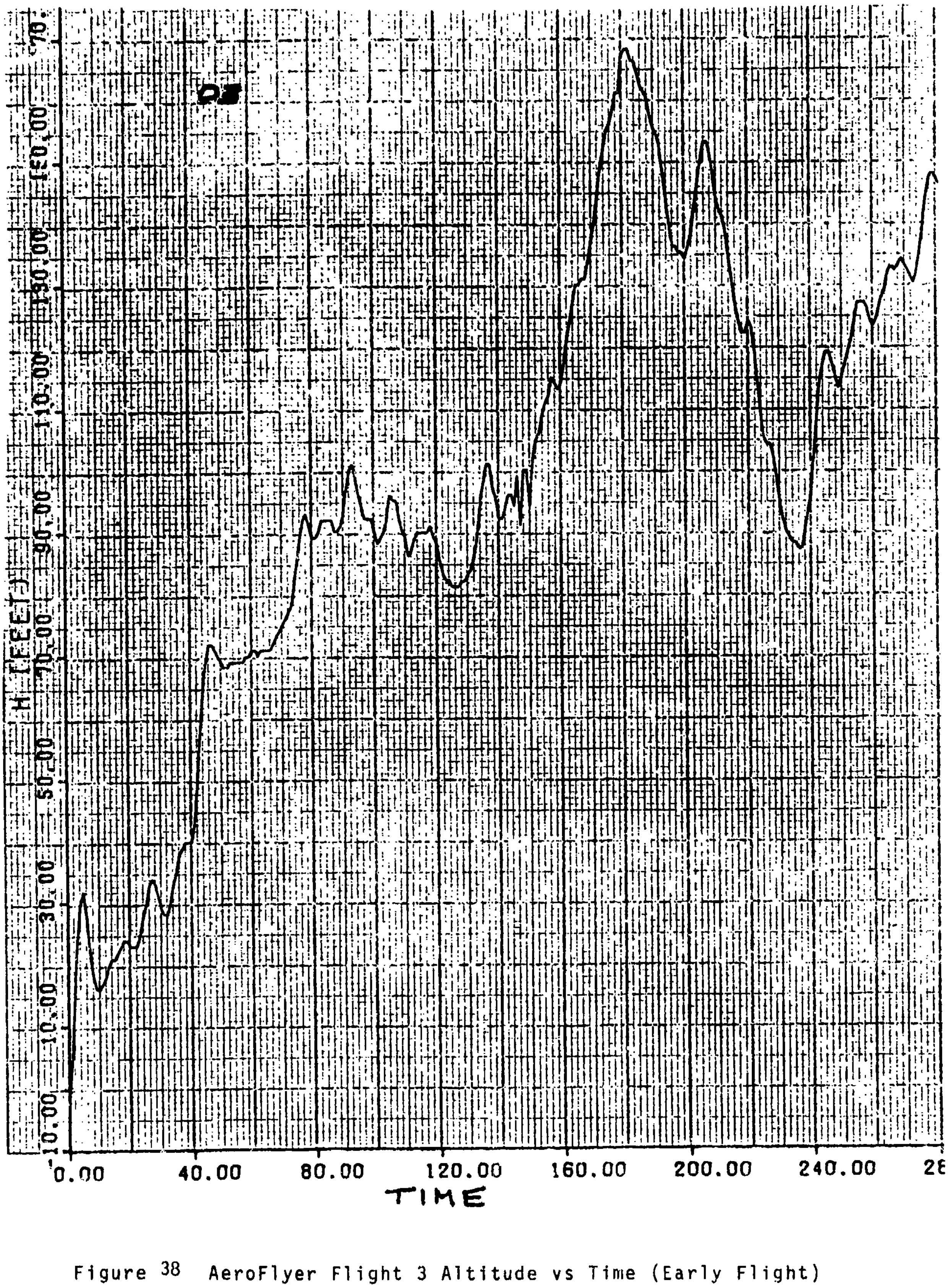

Figure 38 AeroFlyer Flight 3 Altitude vs Time (Early Flight)

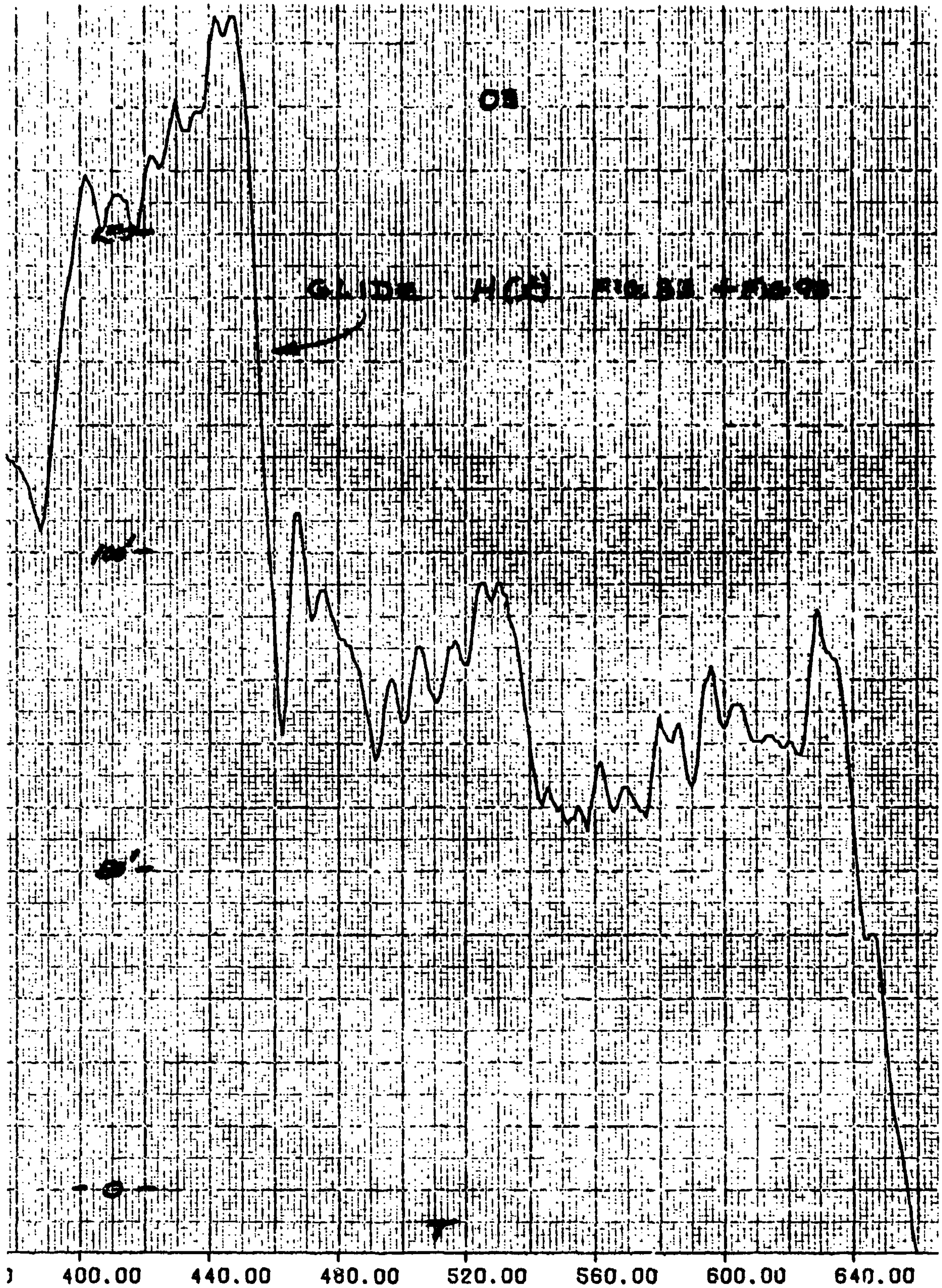

Figure 39 AeroFlyer Flight 3 Gliding Flight

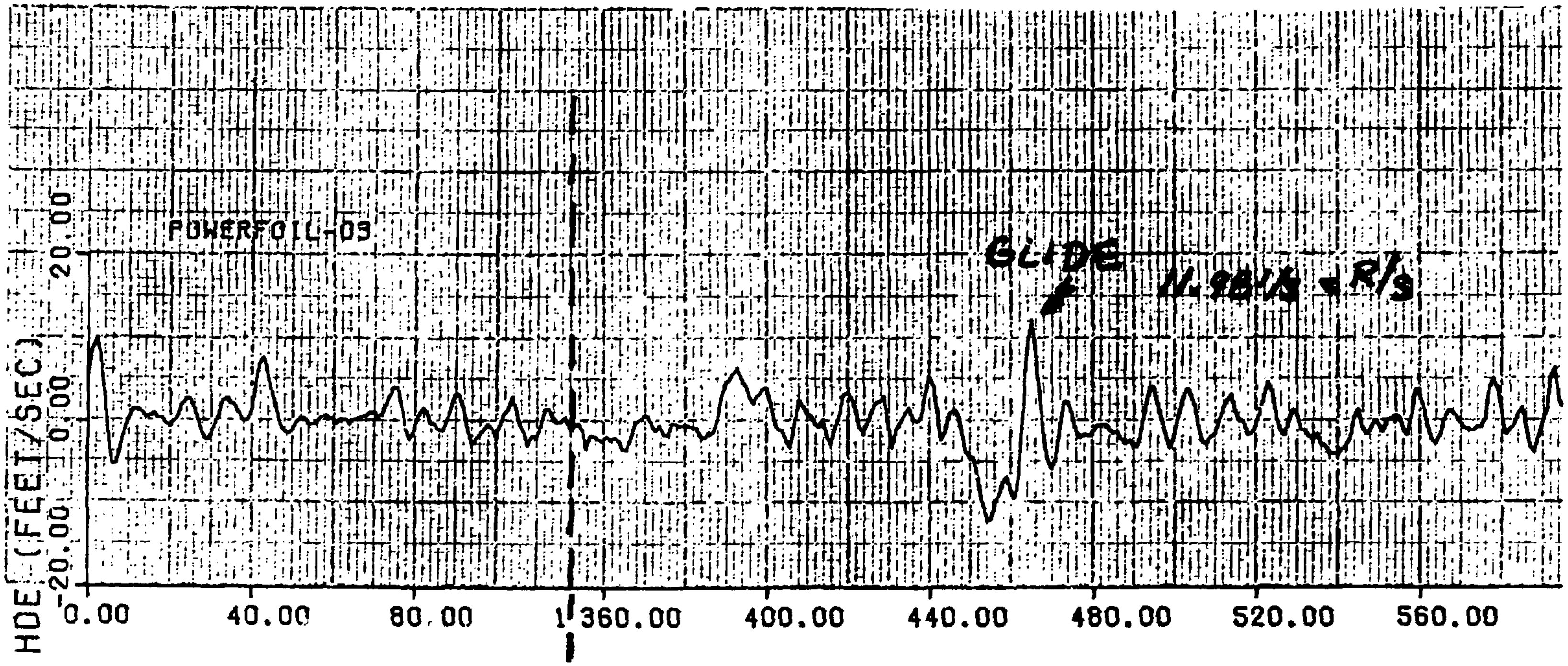

Figure 40 AeroFlyer Flight 3 Rate of Sink and Max Glide

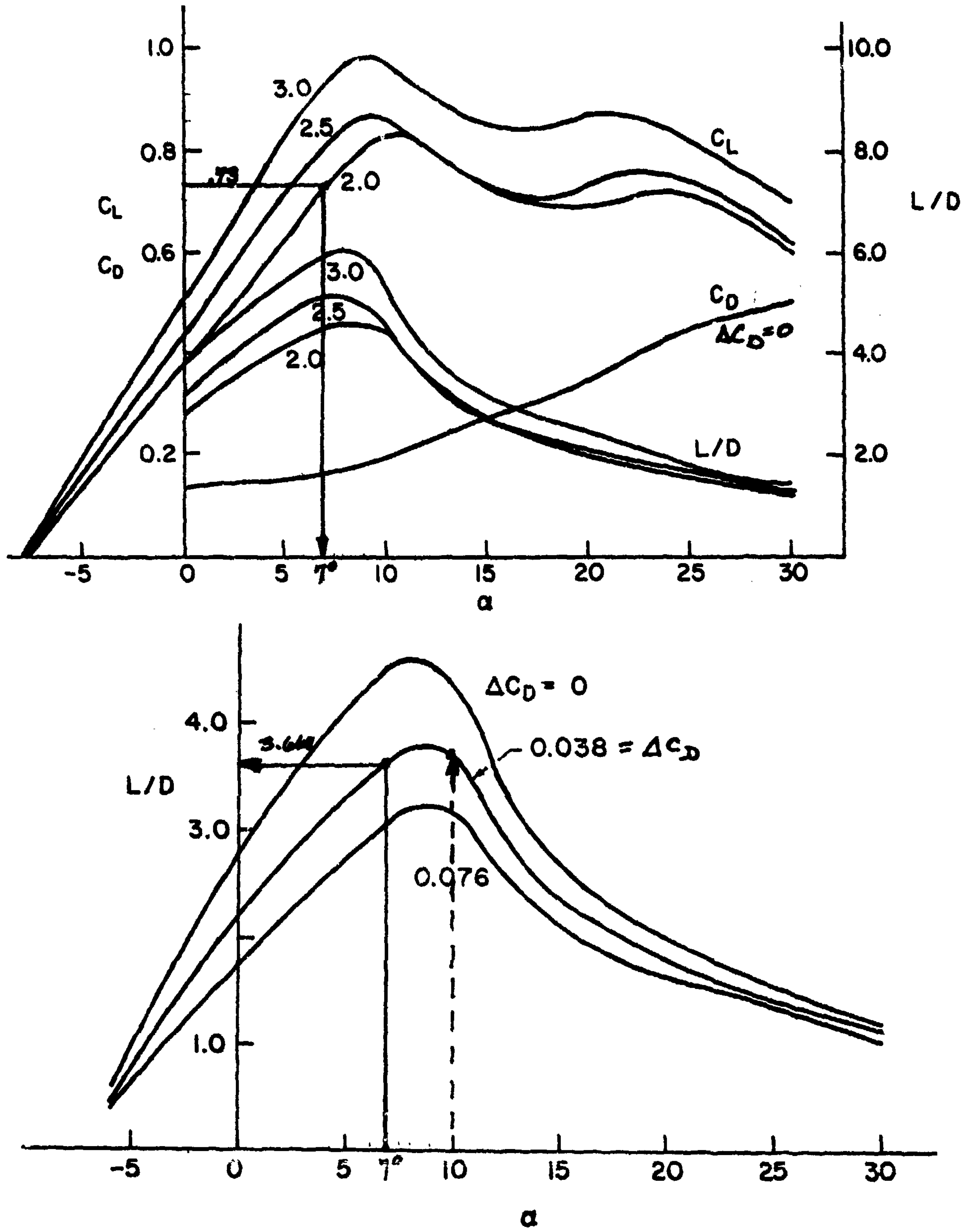

Figure 41 Aerodynamic Data and Performance Data Points

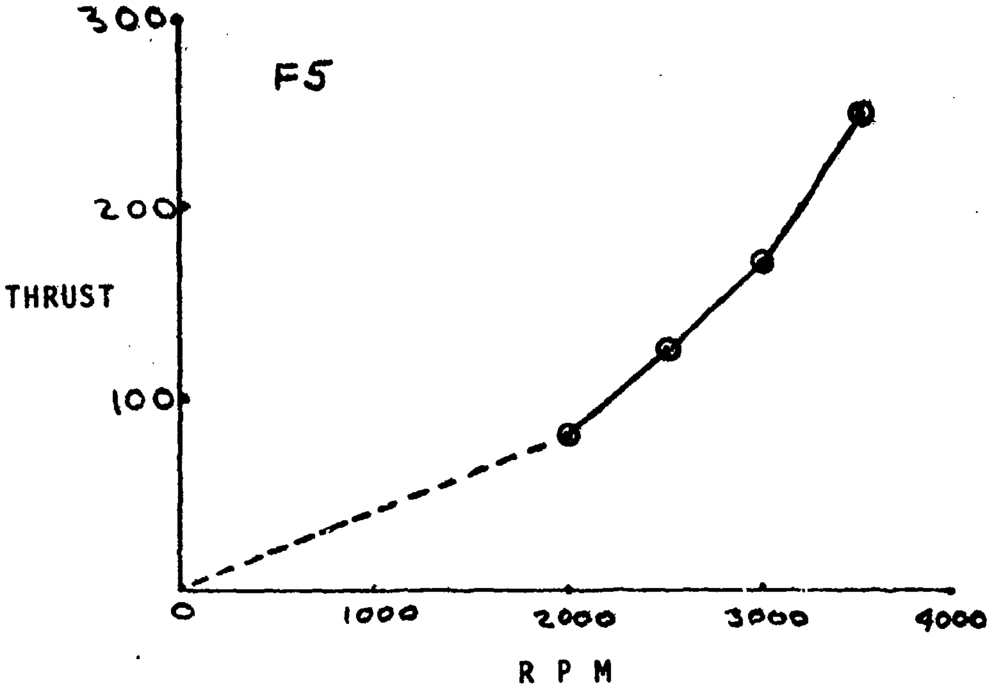

Figure 42 AeroFlyer 5 Static Thrust

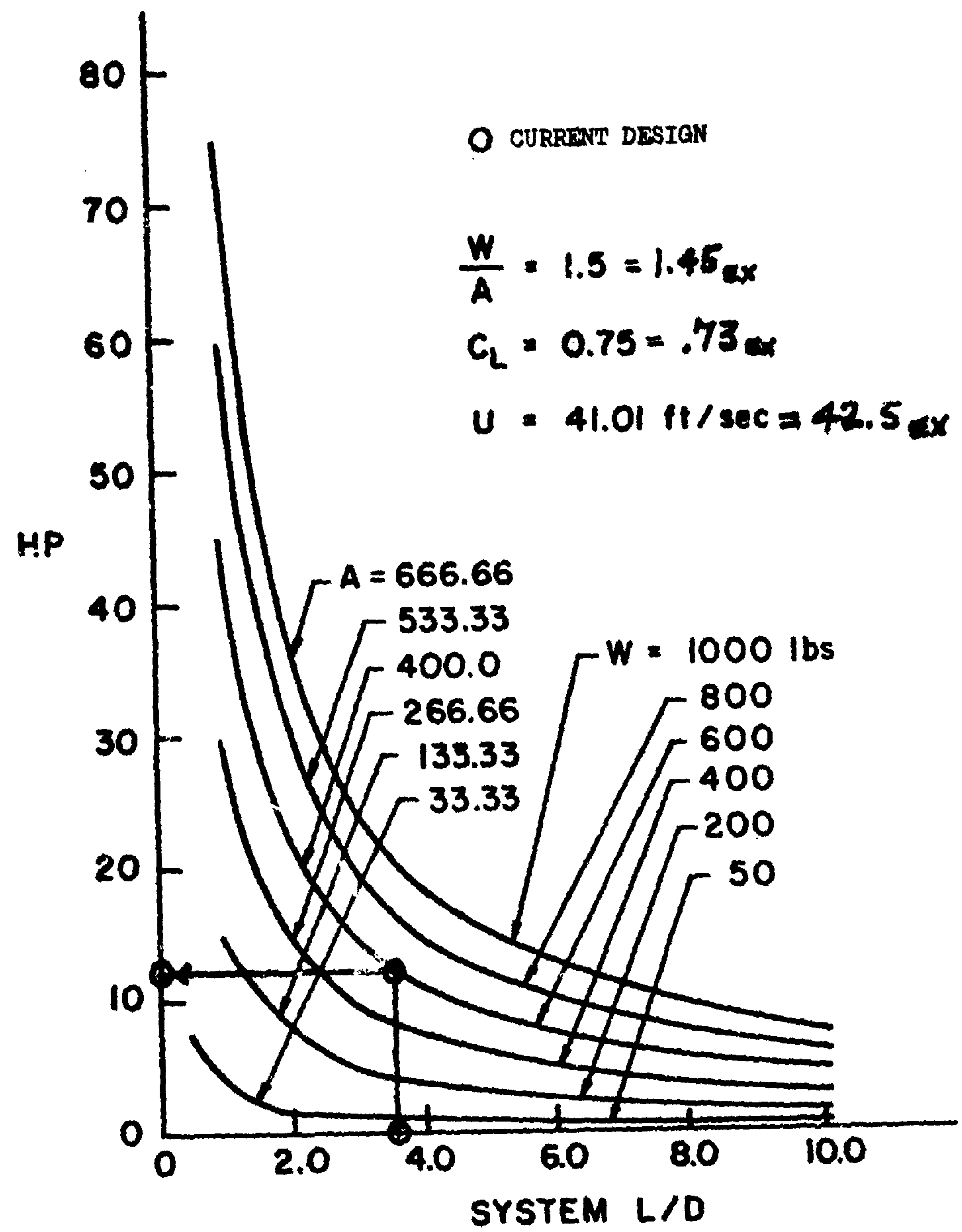

Figure 43 Level Flight Horsepower vs Lift-to-Drag Ratio for W/A = 1.5 and C_L = .75 ($50 \leq W \leq 1{,}000$)

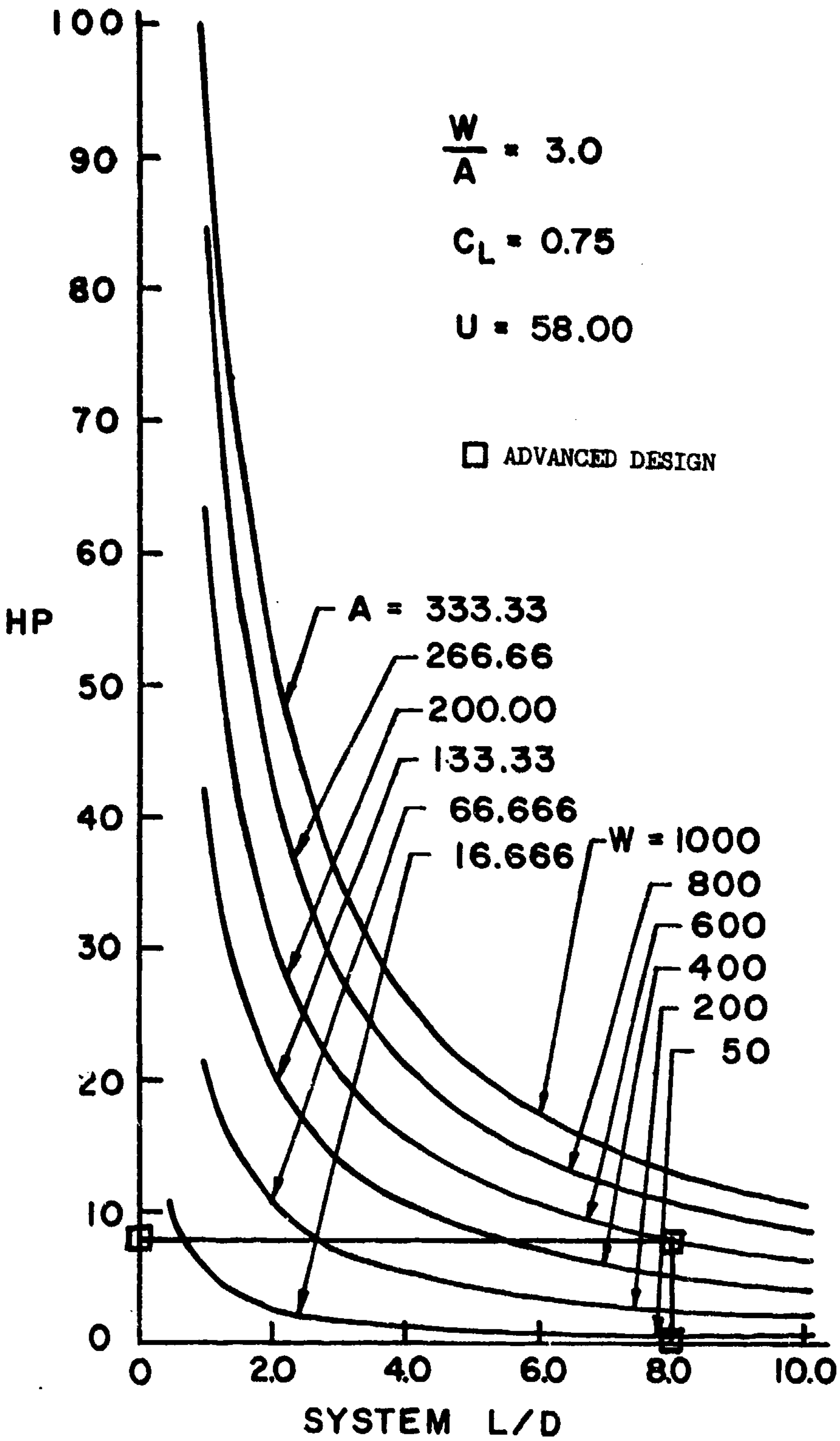

Figure 44 Level Flight Horsepower vs Lift-to-Drag Ratio for W/A = 3.0 and C_L = .75 ($50 \leq W \leq 1,000$)

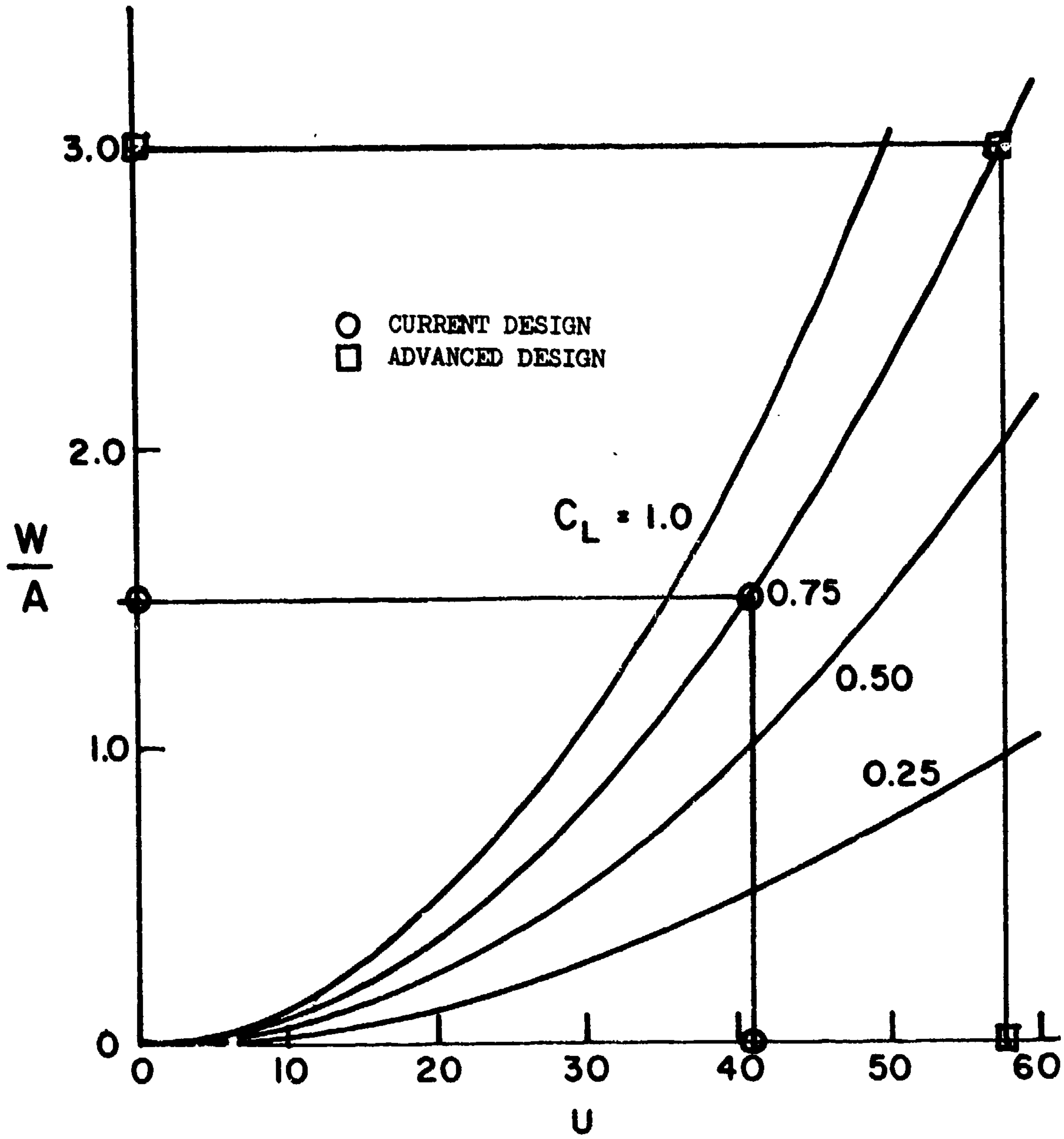

Figure 45 Wing Loading vs Flight Velocity for Various Values of Lift Coefficient ($0 \leq W/A \leq 3$) 2

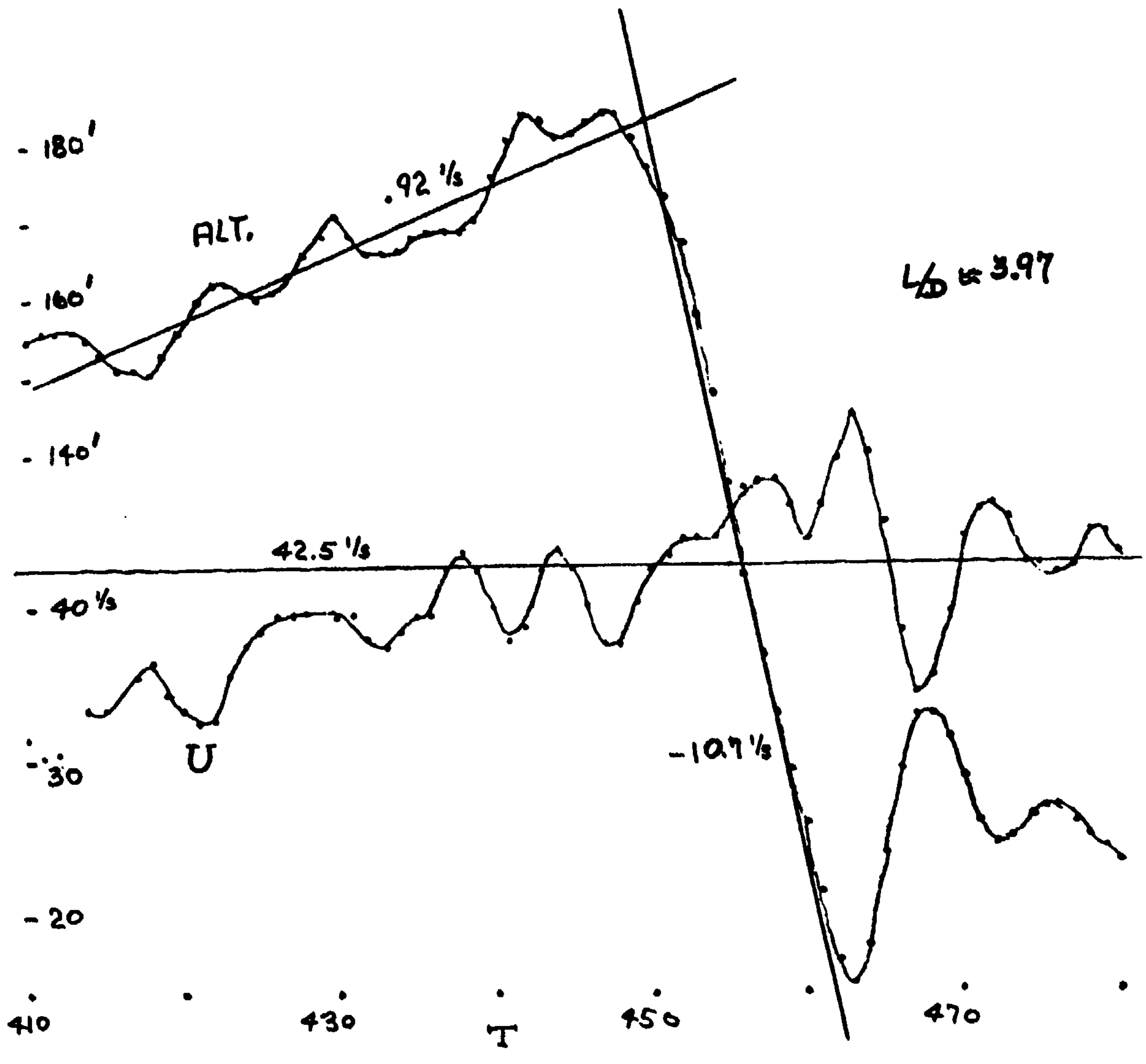

Figure 46 Glide and Phugoid Motion

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